[2120] 鉄筋コンクリートはりのせん断ひびわれでの相対変位

RELATIVE DISPLACEMENT ALONG SHEAR CRACK OF REINFORCED CONCRETE BEAM

Hussein Mokhtar HASSAN* and Tamon UEDA*

1. INTRODUCTION

There have been many researches on flexural and tensile cracks of reinforced concrete members. However, little has been done about shear cracks. In this study, experimental work was conducted to clarify shear crack behaviour of reinforced concrete beam with plain and deformed stirrups. Stirrup strain and vertical deformation of cracked concrete along stirrups in addition to stirrup hook slip, shear crack width and shear displacement along shear crack were measured. Since crack width corresponds to slip of bar at crack, slip-strain relationship at stirrup-crack intersection is looked at in detail. The slip is obtained by integrating the stirrup strain.

2. TEST BEAM, MEASUREMENTS AND LOADING

A reinforced concrete beam, VDPS-13, with dimensions of 200x500x3600 mm containing longitudinal tensile reinforcement 5D25 and compressive reinforcement 2D13 deformed bars. The beam was loaded so as to make shear span to depth ratio equal to 3. One shear span was reinforced by deformed stirrup of diameter 12.56 mm and another with plain stirrup of dimeter 13 mm. The spacing between stirrups was 300 mm. Areas, yield strengths and moduli of elasticity of plain and deformed stirrups were 266 and 253.4 mm^2, 339.7 and 376.3 MPa, and 191.2 and 173.5 GPa, respectively. The concrete strength was 33.1 MPa.

As shown in Fig.1, shear crack width and shear displacement along shear cracks were measured by three sets of contact points cemented to the concrete surface. Wire strain gauges were cemented to measure stirrup strain along stirrups. Also slips of stirrup hooks were measured using steel wire attached to stirrup leg at 4 cm from top of hook.

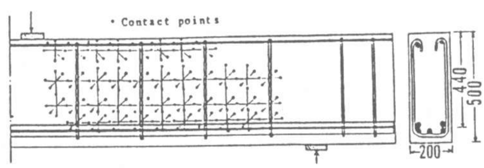

FIG 1. Half elevation and cross section of the beam VDPS-13

The beam was loaded statically during the first 100 cycles and then dynamically with 210 cycles per minute. The dynamic loading was stopped at logarithmic interval so as to take the measurments.

---

* Department of Civil Engineering, University of Tokyo

3. STRAIN DISTRIBUTION OF STIRRUP

Fig.2 displays crack pattern of the tested beam VDPS-13. The left shear span is for deformed stirrups and the right isone for plainstirrups.

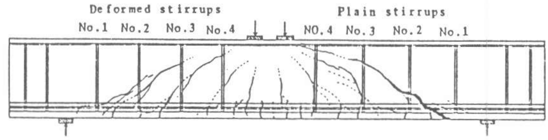

FIG 2. Crack pattern of the beam VDPS-13

Fig.3 shows distribution of the measured strain of plain stirrup No.2 and deformed stirrup No.2 of the beam VDPS-13 at the maximum applied repeated load after 1 and 10000 cycles. It is clear that at crack-stirrup intersection, the strain is greater and decreases toward the hook. The rate of decreasing is greater for deformed stirrup than plain one. This difference is considered to be due to the difference in bond characteristics of stirrup.

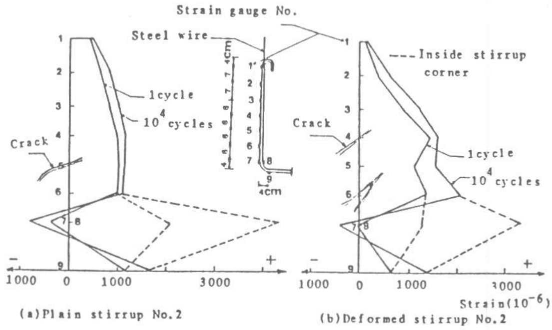

FIG 3. Distribution of stirrup strain

Slip of stirrup at a point can be determined from integral of stirrup strain from the fixed point to the point considered(2). Thus the slip is equal to elongation in a part of stirrup considered. Fig.4 shows relationship between slip and strain of deformed stirrups in the specimen VDPS-13 together with slip-strain curves for deformed bar obtained by the previouspullout tests(2), where slip is modified by using the following equation(2).

$$s = \frac{1000\ S}{D} K_{fc}$$

where

S: slip(mm), D: bar diameter(mm),

$K_{fc} = (f'_c /200)^{2/3}$,

f'_c : concrete strength(kg/cm^2)

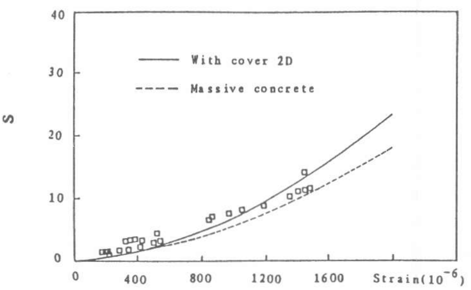

FIG 4. Slip-strain relationship

The slip of deformed stirrup was obtained by integrating measured stirrup strain from the hook to the point cosidered. Strains at starting point of hooks were nearly zero, and no crack crossed stirrup between the hook and the point considered. Strain at dead end of deformed bar in the previous tests were also zero, and there was no crack within embedded length(2). Under such a condition, a unique slip-strain relation is expected(2).The slips of stirrups are closed to slips of bar embedded with concrete cover of 2D which are greater than those of bar embedded in massive concrete. Cover for the stirrups in the beam VDPS-13 was about 2D. This comparison implies that slip-strain relation for deformed stirrup in beam can be predicted by simple pullout test having similar bar arrangement, and that effect of compressive stress in concrete surrounding stirrup is negligible.

Fig.5 indicates slip-strain relationships for deformed stirrups on both the envelope and inner curve of shear force-stirrup strain relationship, which mean under monotonic and cyclic loading, respectively. There seems to be no significant difference in slip-strain relationships between both cases.

All the points of stirrups for slip-strain relation which have been discussed are at some distance from intersection between shear crack and stirrup. Bond deterioration exists in the vicinity of crack intersection, so that slip-strain relationship at crack is expected to be different from that for points at some distance from crack. As shown in Fig.6, slip at crack for the same strain is greater than that at some distance from crack. As expected from Fig.3 and shown in Fig.7, slip of plain stirrup for the same strain is much greater than that of deformed stirrup.

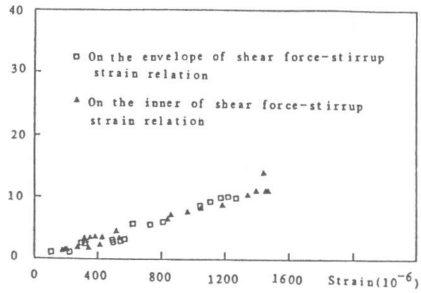

FIG 5. Slip-strain relationship

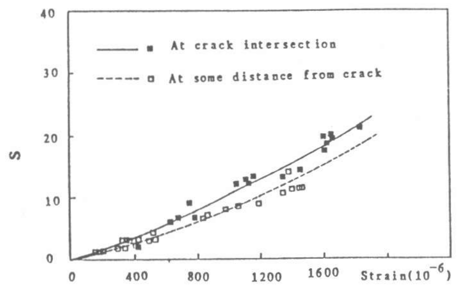

FIG 6. Slip-strain relationship

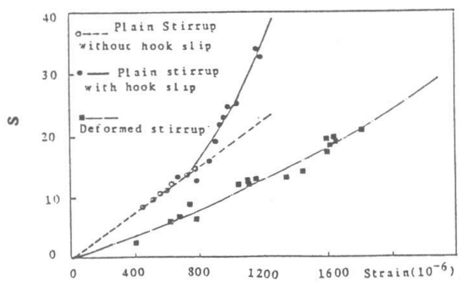

FIG 7. Slip-strain relationship

4. STIRRUP ELONGATION AND CORRESPONDING CONCRETE DEFORMATION

Total elongation of vertical leg of stirrup is obtained by integrating stirrup strain along plain stirrup No.2 and deformed stirrup No.2 of the beam VDPS-13. The corresponding concrete surface deformation including crack displacement in vertical direction along stirrup is obtained from measurements with contact points. Fig.8 shows relationship of vertical concrete deformation and the corresponding stirrup elongation versus logarithm of loading cycles, N. In the light of this figure there is a difference between stirrup elongation and the corresponding concrete deformation as indicated by hatched area. The question is "What are main causes of this difference?".

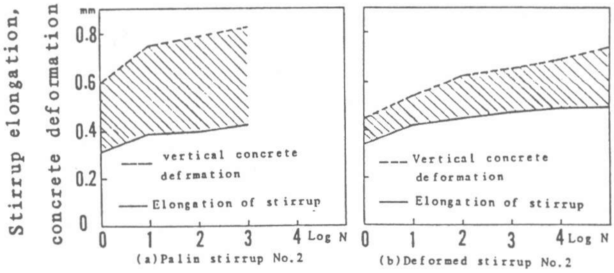

FIG 8. Stirrup elongation and concrete deformation versus Log N

5. ADDITIONAL SLIPS OF STIRRUP

Slips of stirrup hooks of the beam VDPS-13 were measured by thin steel wire welded to stirrup at 4 cm from top of hook. It was found that hook slip is considerable in plain stirrups and much greater when stirrup crossed by a crack closer to hook. No hook slip could be observed for deformed stirrup in this beam.

Fig.9 shows relationship between hook slip for plain stirrups No.2 and No.3 of this beam versus Log N. It is clear that hook slip increases considerably with Log N. Fig.10 shows the relationships between hook slip and stirrup strain for plain stirrups. The stirrup strain is at 11 cm from top of hook. It can be seen that hook slip of plain stirrup starts when the strain is about 500 micro.

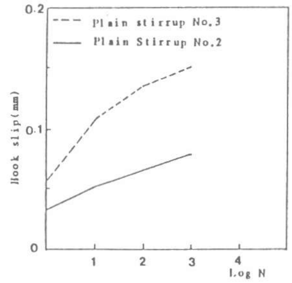

FIG 9. Hook slip versus Log N

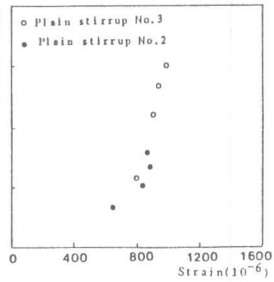

FIG 10. Hook slip versus stirrup strain

Summation of elongation in vertical leg of plain stirrup and hook slip observed is compared with the corresponding vertical concrete deformation in Fig. 11. The difference becomes smaller than that in Fig. 8(a), but does not disappear. The same fact can be seen for deformed stirrup which is shown in Fig. 8(b). This difference seems to be caused by slip of stirrup lower bent portion. Slip of stirrup lower bent portion was observed in the previous study(3).

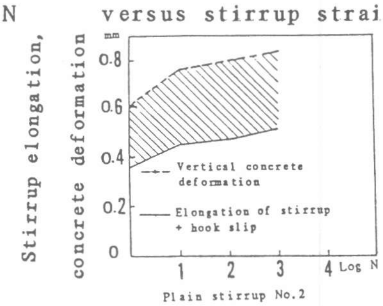

FIG 11. Stirrup elongation and concrete deformation versus Log N

6. SLIP-STRAIN RELATIONSHIP FOR STIRRUP INTERSECTED BY TWO CRACKS

In this section, slip-strain relationship for stirrup intersected by two shear cracks is discussed. For deformed stirrup No.3 of the beam VDPS-13 which was crossed by two shear cracks(see Fig.2), The slip-strain relationship at lower crack stirrup intersection was obtained after slip was calculated by integrating stirrup strain from hook to lower crack-stirrup intersection and subtracting the corresponding vertical displacement of the upper crack obtained from contact point measurements. It can be seen from Fig.12 that the slip-strain relationship for this case, represented by solid squares, is matching with the slip-strain relationship at crack-stirrup intersection for the case of single crack crossing. In this figure, open squares represent slip-strain relationship at lower crack-stirrup intersection without subtracting upper crack vertical displacement.

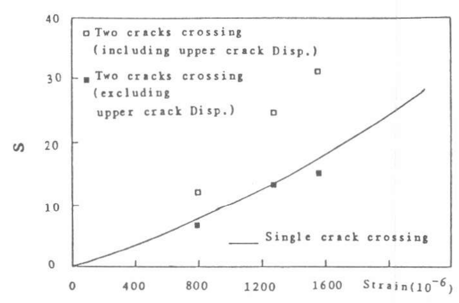

FIG 12. Slip-strain relationship

7. VARIATION OF SHEAR CRACK DISPLACEMENTS ALONG SHEAR CRACK

7.1 VARIATION OF SHEAR CRACK WIDTH ALONG SHEAR CRACK

Variation of shear crack width along shear cracks could be caused by the following two factors.

1) distance to the crack tip, L1

2) distance to the nearst stirrrup, L3 (see Fig.13)

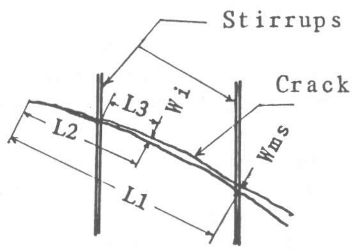

FIG 13 General configration

Fig.14 shows distribution of the measured shear crack widths along main shear crack of beam VDPS-13. From the measured results, the following relation was found.

$$Wi = Wms\,\frac{L2}{L1}\left[1 + A\left(\frac{L3}{L2}\right)^{B}\right]$$

where

L2 > 0, A = 5.69 , B = 2.5

Wms : maximum shear crack width at crack-stirrup intersections

Wi : shear crack width at any position along shear crack

L2 : distance from Wi to the tip of shear crack

Fig.15 shows a comparison between the measured shear crack widths along the main shear crack of the beam VDPS-13 and the corresponding calculated ones using the relation obtained above.

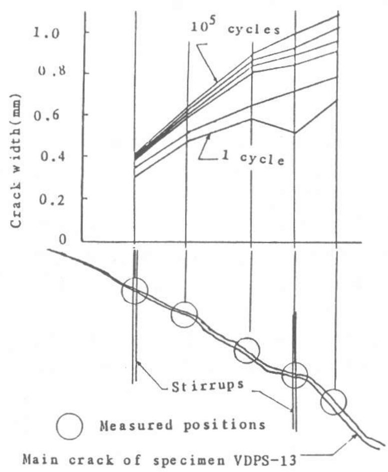

FIG 14. Variation of crack widths along main shear crack of the beam VDPS-13

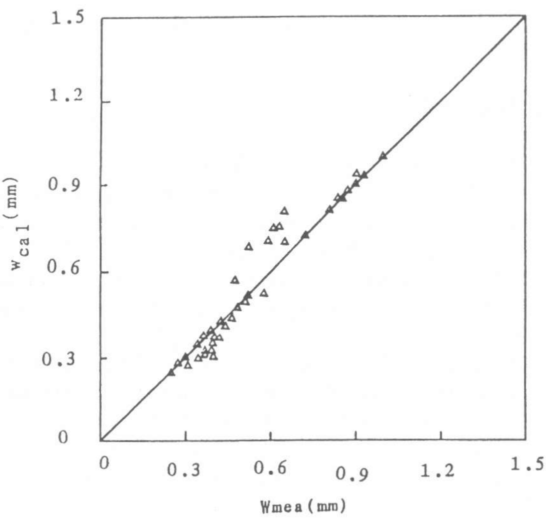

FIG 15. Comparison between Wcal and Wmea

7.2 VARIATION OF SHEAR DISPLACEMENT ALONG SHEAR CRACK

Variation of the shear displacement along shear crack is related to the corresponding crack widths and also affected by distance to the tip of crack and distance to the nearst stirrup. Variation of shear displacement along the main shear crack of the beam VDPS-13 is shown in Fig. 16.

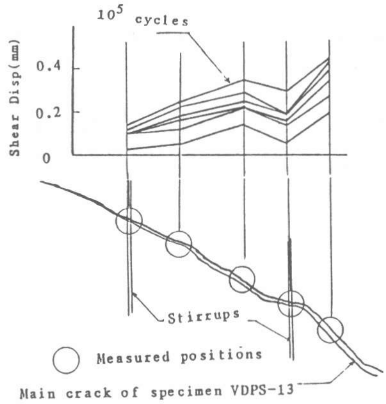

FIG 16. variation of shear displacements along main shear crack of the beam VDPS-13

8. CONCLUSIONS

Based on the experimenal results, the following conclusions can be drawn.

1) Slip-strain relationship for plain and deformed stirrups at crack-stirrup intersection is clarified for static and cyclic loading.
2) Vertical displacement at crack is produced by not only elongation of stirrup leg, but also slips at hook and lower bent portion of stirrup.
3) Variation of width of shear crack and shear displacement along shear crack is dependent on the distances from the position considered to the crack tip as well as to the nearest stirrup.

9. REFFERENCES

(1) HASSAN, Hussein M.,UEDA ,T., TAMAI, S. and OKAMURA, H. : Fatigue Test of Reinforced concrete Beams with Various Types of Shear Reinforcement, Transactions of JCI, Vol. 7, 1985.

(2) NIWA, J., CHOU, L.L., SHIMA, H. and OKAMURA, H. : Strain-Slip Relationship of deformed bar, Seminar on Finite Element Analysis of Reinforced Concrete Structures, Tokyo, May, 1985, Vol.2 , JCI, PP. 227-235.

(3) KAMEDA, T. and OGURA, K. : Experimental Study on Anchorage Capacity of Various Hook Shapes for Shear Reinforcement Bars of R.C. Members, JCI 8th Conference, 1986(in Japanese).

(4) MIRZA, M.S. and HOUDE, J. : Study of Bond Stress-Slip Relationship in Reinforced Concrete, ACI Journal, Vol. 76, No.1, January 1979, PP. 19-46.