Two-Piece U-Stirrups in Reinforced Concrete Beams

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One rectangular beam with two-piece lapped U-stirrups was tested in shear and compared with a control beam having one-piece closed stirrups.

Two L-beams with two-piece closed smooth stirrups were tested in combined bending, shear and torsion and compared with companion control specimens having one-piece closed stirrups. Only a slight loss of strength and ductility was noticed in beams with two-piece closed stirrups. This loss was not so significant as to preclude the use of two-piece closed stirrups, which alleviate the problem of placing reinforcement in many congested areas.

Keywords: beams (supports); bending; ductility; L-beams; rectangular beams; reinforced concrete; reinforcing steel; research; shear; stirrups; strength; torsion.

The use of one-piece closed stirrups leads to difficulty in placement of reinforcement at some congested joint details in concrete structures. Adoption of two-piece closed U-stirrups may alleviate some of these difficulties, in addition to making cage preparation easier. ACI 318-63[1] is silent about the use of two-piece stirrups. Research data on the performance of two-piece closed stirrups are meager.

To sample the performance of two-piece U-stirrups in shear and torsion six beams were tested; three with two-piece stirrups and three companion control specimens with one-piece closed stirrups. Two of these beams were rectangular and were tested in shear (unaccompanied by torsion), the specimen details, test set-up and test results being as per Fig. 1 and 2 and Table 1. The other four beams were L-shaped and were tested in combined bending, shear, and torsion. The specimen details, loading set-up and results are given in Fig. 3 and 4 and Table 2.

The rectangular beam with one-piece stirrups failed at 95 percent of its rated shear (as per ACI 318-63)

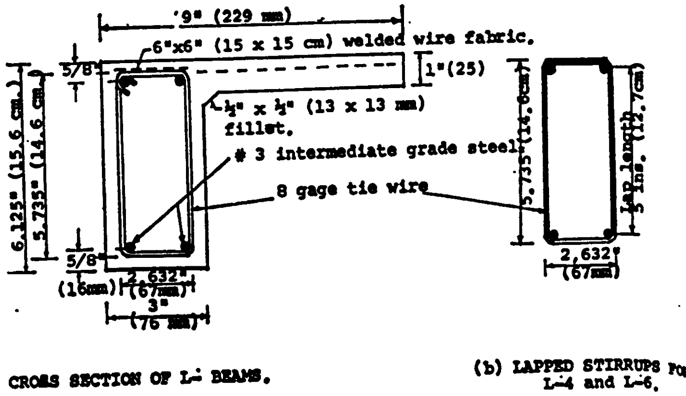

Fig. 3—Details of L-beams

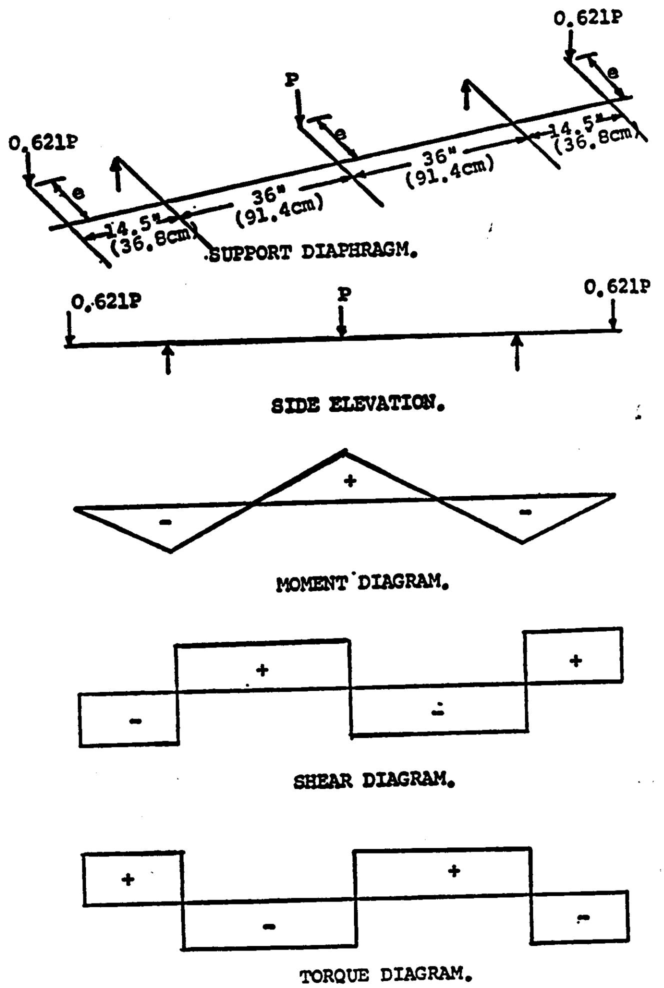

Fig. 4—Schematic diagram of loading set up for L-beams ($M/Vd = 3$)

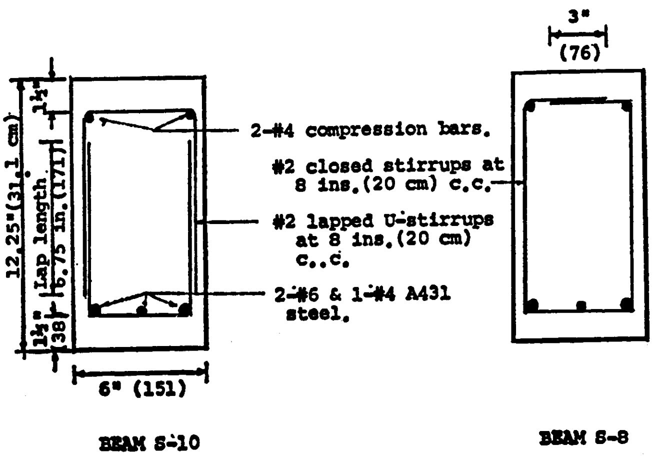

Fig. 1—Details of rectangular beams

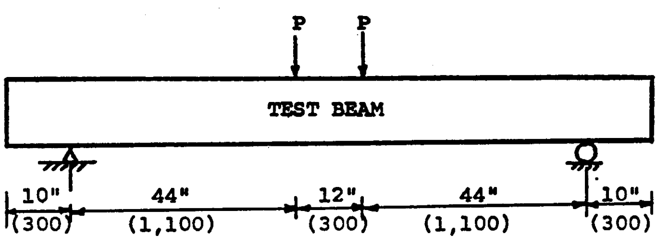

Fig. 2—Loading set up for rectangular beams

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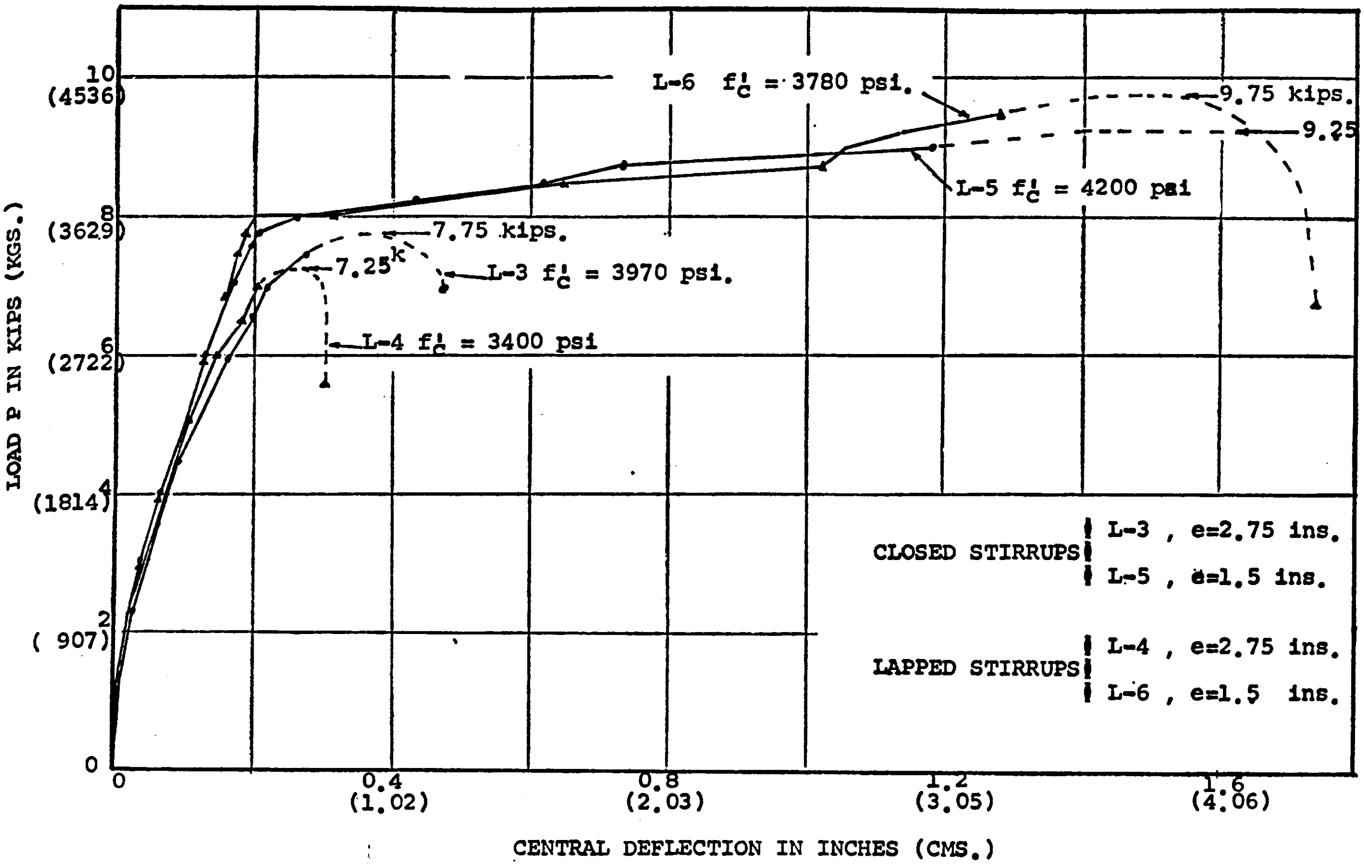

Fig. 5—Load-deflection diagrams for L-beams

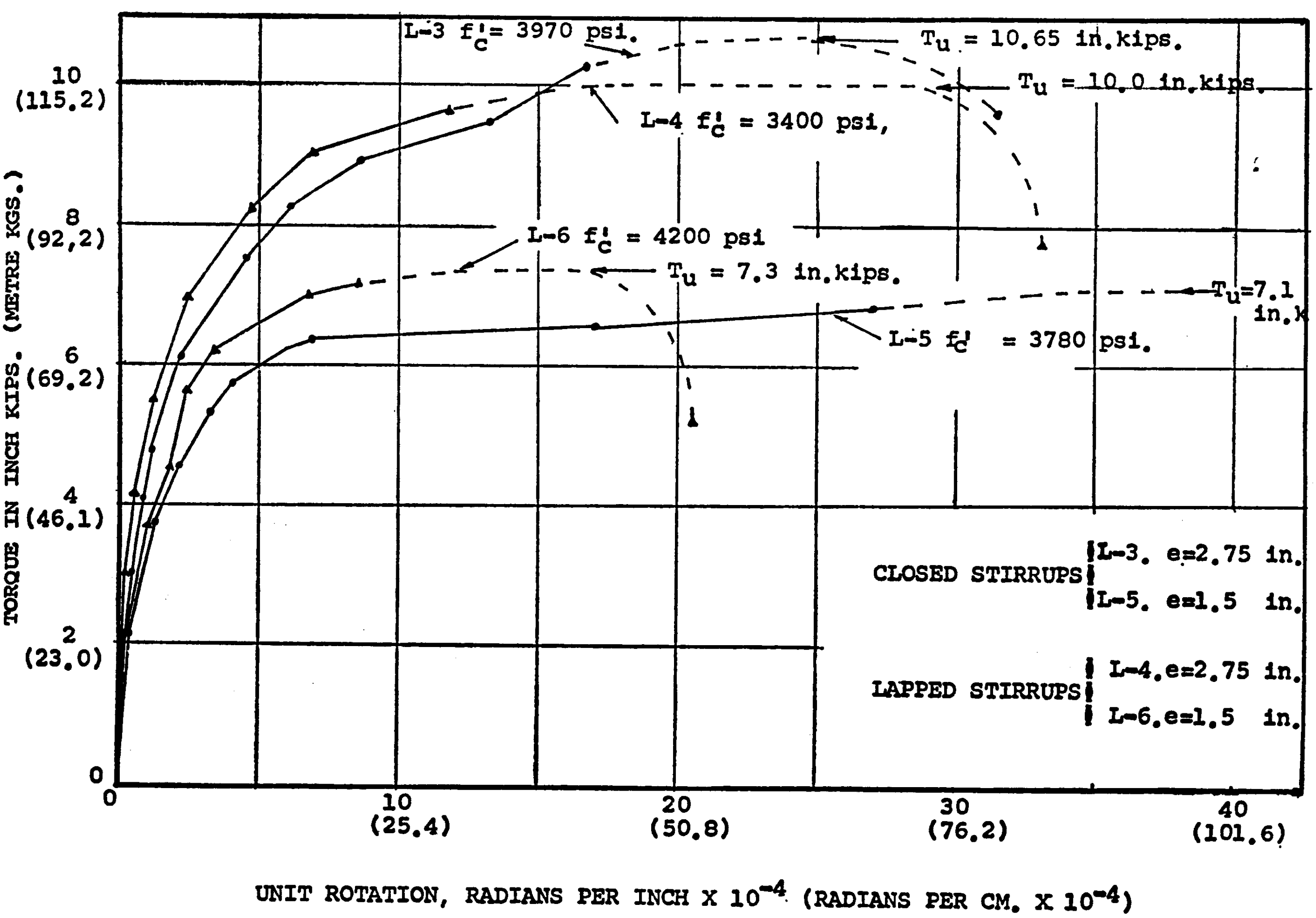

Fig. 6—Torque-rotation diagrams for L-beams

TABLE 1—SPECIMEN DETAILS AND TEST RESULTS OF RECTANGULAR BEAMS

Beam No.	Percentage of reinforcement	Yield strength of stirrup steel f_{ys}, ksi (kgf/cm²)	rf_{ys}, psi (kgf/cm²)	Concrete			Type of stirrups	Shear-span-to-depth ratio a/d	Ultimate shear V_u, kips (kg)	Ultimate shear stress v_u, psi (kgf/cm²)	Rated shear stress $2\sqrt{f_c'} + rf_{ys}$, psi (kgf/cm²)	$\frac{v_u}{(2\sqrt{f_c'} + rf_{ys})}$
				f_c', psi (kgf/cm²)	f_R', psi (kgf/cm²)	f_{sp}', psi (kgf/cm²)						
S-8	0.0174	50.0 (3515)	105 (7.38)	3920 (276)	590 (41.5)	396 (27.8)	One piece	4.20	13.58 (6160)	218 (15.3)	230 (16.2)	0.95
S-10	0.0171	50.0 (3515)	105 (7.38)	4920 (346)	679 (48.7)	444 (31.2)	Lapped two piece	4.16	13.50 (6123)	214 (15.0)	245 (17.2)	0.88

TABLE 2—SPECIMEN DETAILS AND TEST RESULTS FOR L-BEAMS

Beam No.	Type of stirrup	Concrete			Stirrups as per Mattock rf_{ys},* psi (kgf/cm²)	Eccentricity e, in. (cm)	Ultimate Shear V_u, lb (kg)	Ultimate torque T_u, in.-lb (m-kg)	V_u/V_o, percent	Ultimate shear stress v_u, psi (kgf/cm²)	Ultimate torsional stress τ_u, psi (kgf/cm²)
		f_c', psi (kgf/cm²)	f_R', psi (kgf/cm²)	f_{sp}', psi (kgf/cm²)							
L-3	One piece	3970 (279)	490 (34.5)	427 (30.0)	456 (32.0)	2.75 (7.00)	3875 (1757)	10,650 (122.7)	71.7	235 (16.5)	410 (28.8)
L-4	Lapped Two piece	3400 (239)	520 (36.6)	350 (24.6)	430 (30.2)	2.75 (7.00)	3625 (1644)	9,980 (115.0)	68.6	220 (15.5)	384 (27.0)
L-5	One piece	3780 (266)	532 (37.4)	381 (26.8)	395 (27.8)	1.50 (3.81)	4750 (2155)	7,120 (82.0)	88.7	288 (20.2)	274 (19.3)
L-6	Lapped two piece	4200 (k95)	540 (38.0)	439 (30.9)	400 (28.1)	1.50 (3.81)	4875 (2211)	7,300 (84.1)	87.6	295 (20.7)	281 (19.8)

All beams have $p_w = p_w' = 0.0132$; $f_y = 59.3$ ksi (4169 kgf/cm²); $r = 0.0046$; $rf_{ys} = 204$ psi (14.34 kgf/cm²)

*Stirrups specified for attained T_u and V_u by L-3 through L-6 by Mattock's proposal.[2]

and that with two-piece lapped stirrups at 87 percent. (The stirrup spacing of about $0.75d$ in these rectangular beams was more than ACI 318-63 would permit.) The 8 percent loss of rated strength due to lapping of two-piece stirrups should not preclude such use, and may merely indicate insufficient lap.

L-beams L-3 and L-4 had a relatively high torque-to-shear ratio [$T/V = 2.75$ in. (7 cm)]. The beam with one-piece stirrups, L-3, reached a V_u/V_o (the ratio of ultimate shear on the beam in the combined shear-torsion loading to the rated shear without torsion) of 71.7 percent, compared to 68.6 percent for L-4, the beam with two-piece stirrups. For the complex crack pattern and internal stress situation this loss of only 4.3 percent does not appear significant.

Beams L-5 with one-piece stirrups and L-6 with two-piece stirrups had moderate torque-to-shear ratio [$T/V = 1.5$ in. (3.8 cm)]. They failed at almost the same V_u/V_o values.

Table 2 shows the specified stirrups (rf_{ys}) to sustain the given ultimate loads, as per Mattock's proposal.[2] The stirrups actually provided ($rf_{ys} = 204$ psi) are substantially less than he would specify.

For the ductility of these L-beams both the load-deflection and torque-rotation curves (Fig. 5 and 6) should be considered, the emphasis being dependent on the torque-shear ratio. Although the beams with two-piece stirrups, L-4 and L-6, showed a loss of ductility when compared with L-3 and L-5, the ductility exhibited by L-3 and L-4 in torsion and L-5 and L-6 in shear is by no means inadequate. Crack width measurements indicated that the stirrups probably yielded in all these four beams before failure. Although preceded by considerable ductility, the final failure of beam L-6 was violent, accompanied by spalling of concrete and exposure of a two-piece closed stirrup, perhaps due to inadequate lap.

In all three beams with two-piece closed stirrups, the lap lengths were inadequate under the provisions of the code (ACI 318-1963). This should not be taken to mean that the bond requirements may not be critical especially in larger beams.

CONCLUSIONS

1. Two-piece closed stirrups even in cases of combined shear and torsion seemed adequate.
2. The slight loss of ductility and strength shown in these tests could be taken care of by a smaller ϕ factor or by a more effective lap length.
3. The required lap lengths for larger sized beams and/or other types of loading might need more study.

ACKNOWLEDGMENT

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2. Mattock, Alan H., "How to Design for Torsion," *Torsion of Structural Concrete*, ACI Special Publication No. 18, American Concrete Institute, Detroit, 1968, pp. 469-495.

APPENDIX—NOTATION

e = ratio of torque to shear
f_c' = cylinder strength of concrete in compression
f_R' = modulus of rupture of concrete
f_{sp}' = splitting tensile strength of concrete
f_y = yield strength of longitudinal reinforcement
f_{ys} = yield strength of stirrup steel
J_p = plastic torsion modulus based on sand-heap analogy
p = A_s/bd
p_w = $A_s/b'd$
p_w' = $A_s'/b'd$
r = area of both legs of stirrup steel/($b' \times$ spacing)
T_u = total ultimate torque
V_o = $(2\sqrt{f_c'} + rf_{ys})b'd$
V_u = total ultimate shear
v_u = $V_u/b'd$
τ_u = ultimate torsional shear stress (plastic) = T_u/J_p