3. With the length of lap splice more than 40d, the full tensile force could be transferred.
4. The unit bond strength tended to increase with the increasing in bond length and lap splice length, but decrease for lap splice length between 40d and 60d.
5. For the bond tests of beam and truss types, it was not necessary to reinforce the ends of the FRP bars. This test method for researching the bond characteristic was wholly effective.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Shimizu Construction, Kumagaiguimi Co., Okumuragumi Constrution Co., and Mitsubishikasei Co., which provided the FRP bars.

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TABLE 1—CONSTITUTION AND SHAPE OF FRP BAR

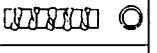
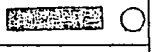
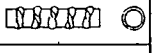
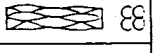
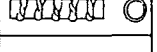
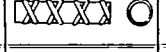
Fiber	Denomination of specimens		Shape of surface and cross section of FRP bars	Fiber content by volume (%)	Bond length			Constitution of FRP bars
					10d	20d	30d	
Carbon	C-1	○		60	○	○	○	Carbon fiber is wound spirally round a bar
	C-2	△			○	○	○	Sand is stuch to the surface of a bar
	C-3	□			○	○	○	A bar is constituted of seven strands twisted
	C-4	△			○	○	○	A bar is formed to the braid on which sand is stuch
Aramid	A-1	⬭			○	○	○	Aramid fiber is wound spirally round a bar
	A-2	⬠			○	○	○	A bar is formed to the braid on which sand is stuch
	A-3	⬡			○	○	○	A bar is formed to the braid
Glass	G-1	◇			○	○	○	Glass fiber is wound spirally round a bar
Vinylon	V-1	○			○	○	○	The crossed vinyron fibers are wound round a bar
Steel	D10	☆	—		○	○	—	Deformed bar

TABLE 2—RESULTS OF BOND TEST

Bond length (cm)	Fiber	Specimens	Compressive strength of concrete (N/mm^2)	Maximum tensile force (kN)	Tensile stress (N/mm^2)	Bond strength (N/mm^2)	Failure mode
40	Carbon	C 1	26.0	134	1490	-	rupture
		C 2	33.7	127	1150	-	〃
		C 3	29.4	67	-	5.1	pull out
		C 4	34.7	136	1090	-	rupture
	Aramid	A 1	28.9	112	1400	-	〃
		A 2	30.1	122	1020	-	〃
		A 3	27.3	94	-	7.0	pull out
	Glass	G 1	30.9	97	881	-	rupture
	Vinylon	V 1	27.1	48	505	-	〃
20	Carbon	C 1	26.6	77	-	11.4	pull out
		C 2	28.9	79	-	10.6	〃
		C 3	27.9	37	-	5.6	〃
		C 4	33.2	84	-	10.6	〃
	Aramid	A 1	31.3	60	-	9.4	〃
		A 2	31.8	96	-	12.3	〃
		A 3	30.1	60	-	9.0	〃
	Glass	G 1	26.0	85	770	-	rupture
	Vinylon	V 1	28.3	48	-	7.0	pull out
	Steel	D 10	28.8	40	562	-	rupture
10	Carbon	C 1	28.8	45	-	13.4	pull out
		C 2	26.6	51	-	13.6	〃
		C 3	26.9	13	-	4.1	〃
		C 4	30.0	63	-	15.9	〃
	Aramid	A 1	25.1	51	-	16.0	〃
		A 2	29.3	72	-	18.7	〃
		A 3	29.1	40	-	11.9	〃
	Glass	G 1	29.5	56	-	15.0	〃
	Vinylon	V 1	29.5	31	-	8.8	〃
	Steel	D 10	27.1	12	539	-	rupture

TABLE 3—DATA OBTAINED WITH TRUSS TYPE OF SPECIMENS

Spesimen	Lapped splice length (cm)	Maximum load (kN)	Tensile strength of FRP bar (N/mm^2)	Unit bond strength of FRP bar (N/mm^2)	Failure mode
C-M-10	8(10d)	18.0	345	8.7	Pull-out
C-M-15	12(15d)	30.9	592	10.2	Pull-out
C-M-20	16(20d)	45.6	874	11.0	Pull-out
C-M-25	20(25d)	60.8	1170	11.8	Pull-out
C-M-30	24(30d)	77.6	1490	12.5	Pull-out
C-M-40	32(40d)	107.0	2060	13.0	Pull-out
C-M-50	40(50d)	116.0	2220	11.3	Pull-out
C-M-60	48(60d)	101.0	1950	8.2	Pull-out

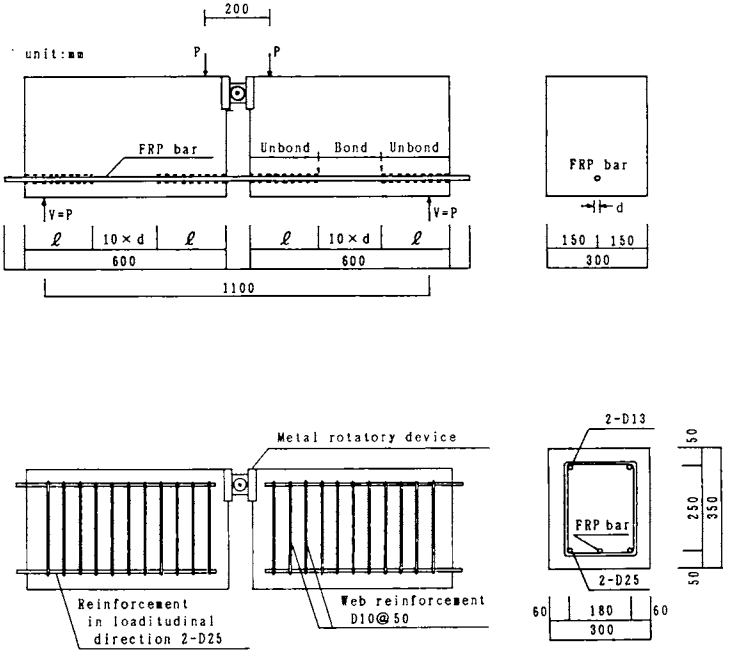


Fig. 1—Equilibrium requirements in the beam-type specimen

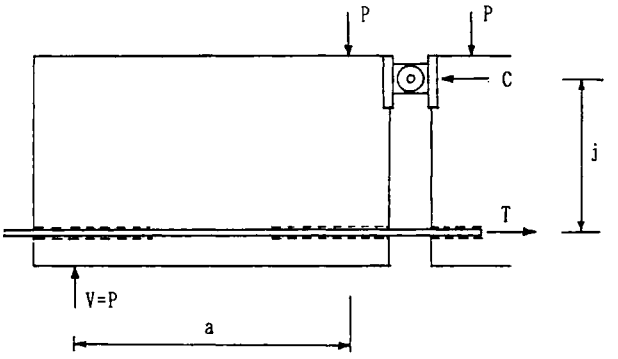


Fig. 2—Details of specimen

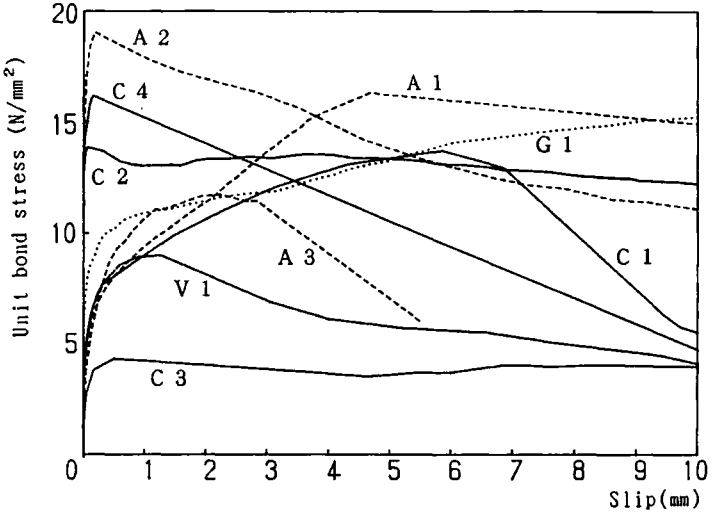


Fig. 3—Unit bond stress and slip curves for bond length of 10*d*

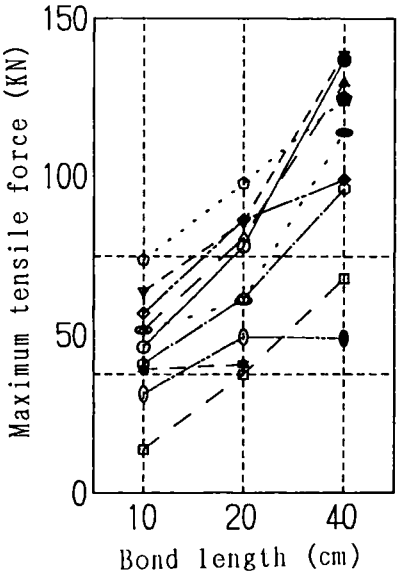


Fig. 4—Relationship between maximum tensile force and bond length

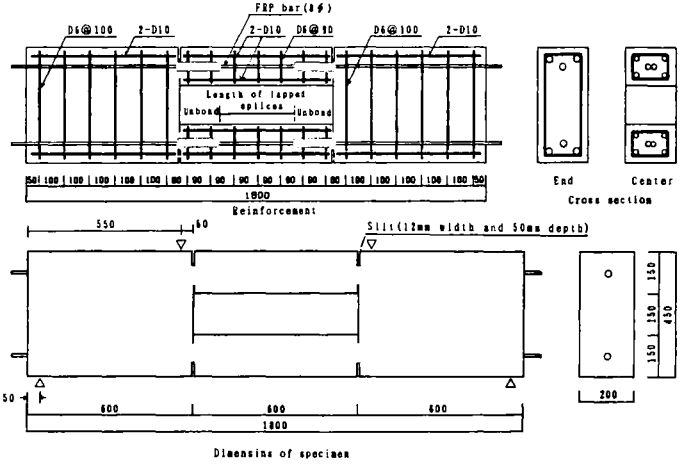


Fig. 5—Details of specimen for lapped splice test

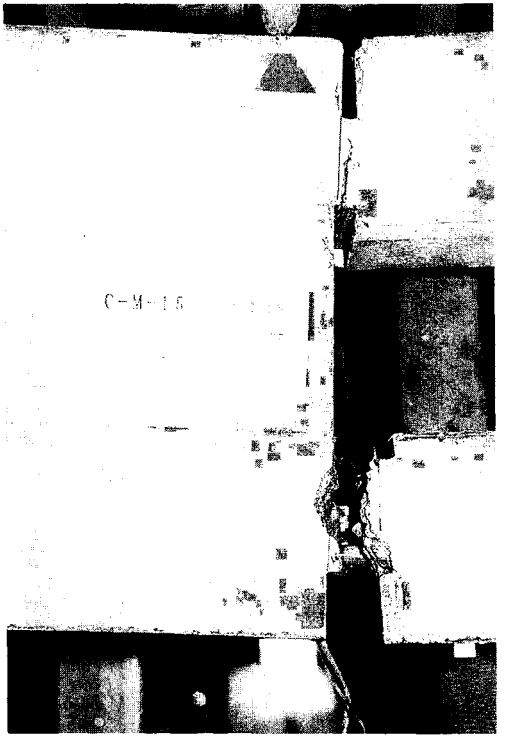


Fig. 6—State of a crack at the bottom slit

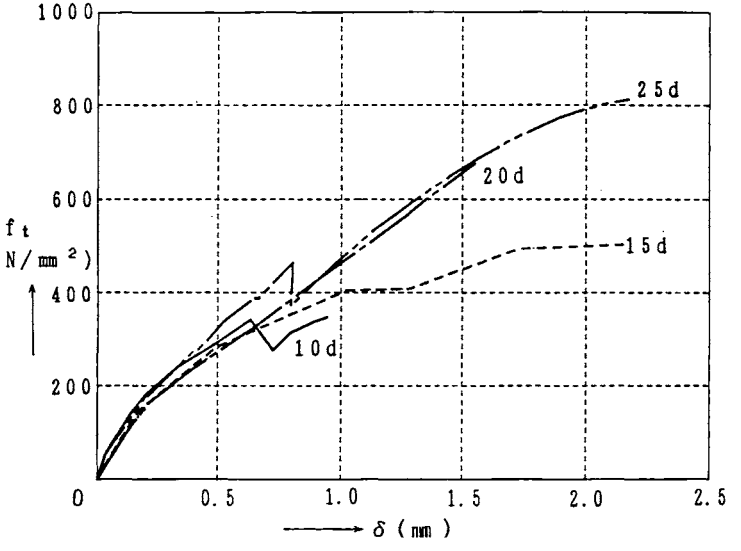


Fig. 7—Tensile stress of FRP bar and crack stretch curves at slit

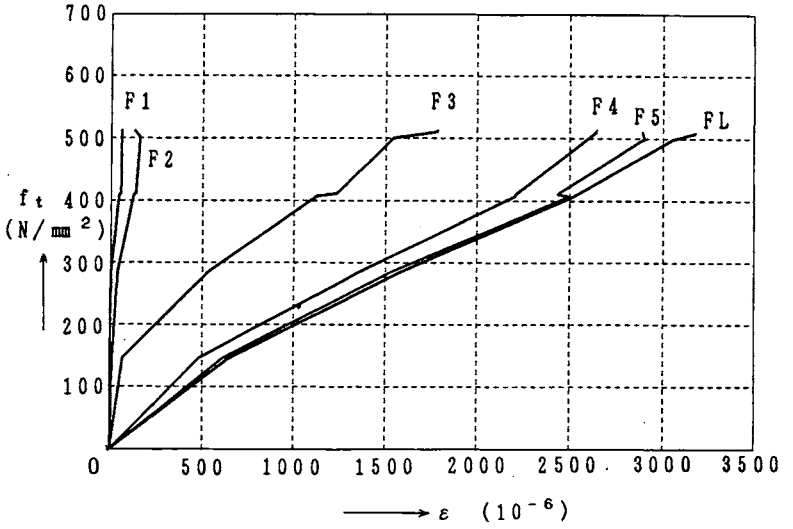


Fig. 8—Tensile stress and strain curves for lapped splice length of 15*d*

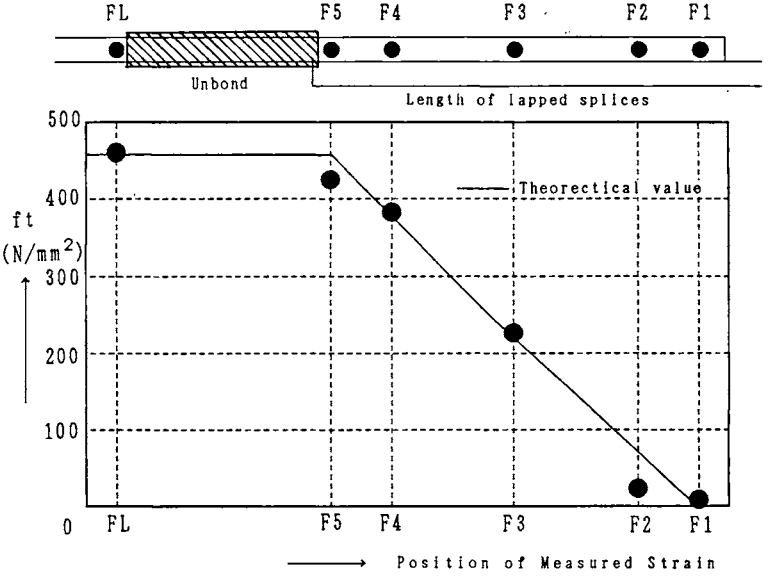


Fig. 9—Distribution of strain for tensile force at pulling-out

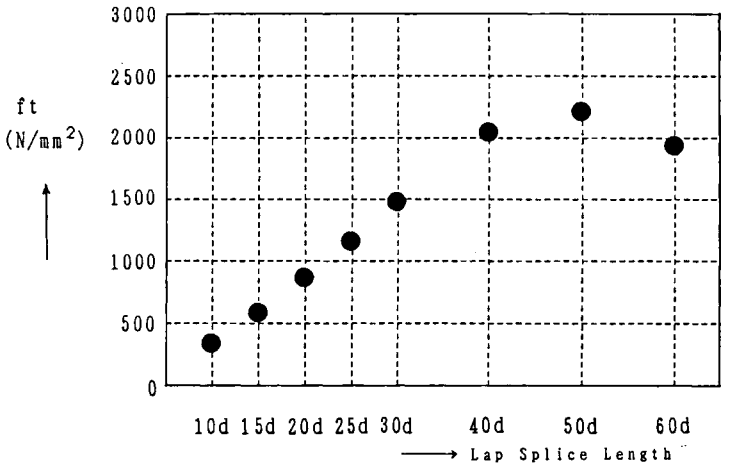


Fig. 10—Relationship between tensile stress at pull-out and lapped splice length

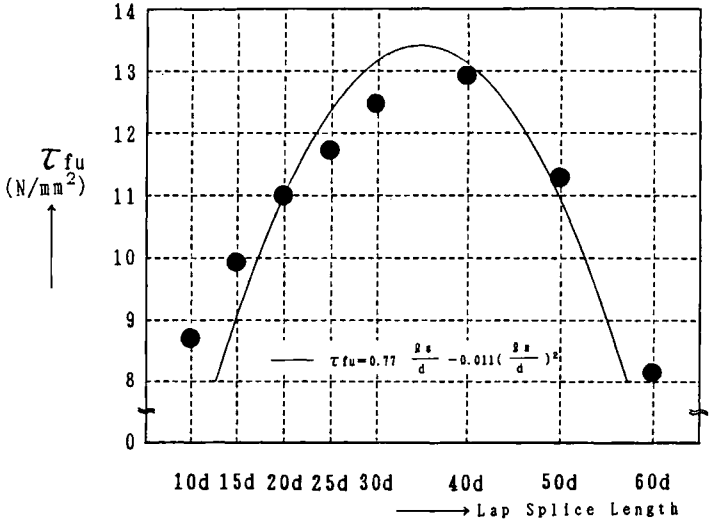


Fig. 11—Relationship between unit bond stress and lapped splice length

Bond of GFRP Rebars to Ordinary-Strength Concrete

by M.R. Ehsani, H. Saadatmanesh, and S. Tao

Synopsis: An overview of a study on bond of Glass-fiber-reinforced-plastic (GFRP) rebars to concrete is presented. The 78 specimens to be tested include several variables, such as the mode of failure (i.e. pullout or splitting), concrete compressive strength, bar diameter, clear cover distance, and top bar effects. In addition, the effect of the radius of bend for hooked bars and the extension on the hooks is being investigated. The study is currently in progress and the results of the specimens tested to date are presented. Preliminary results indicate that the top bar effect observed for steel rebars is also present for GFRP bars. For hooked bars, larger radii of curvature increases the failure load of the bars significantly.

Keywords: Bending; bond strength; compressive strength; cover; fiber reinforced plastics; glass fibers; pullout tests; rebars; slippage; splitting stresses