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論 文

[2210] Experimental Study on Transfer Length of Pretension Concrete Members with Various FRP Rods

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1. INTRODUCTION

Recently, many researches have been made on FRP rods for reinforcement of reinforced and prestressed concrete structures. Last year, the symposium on the advancement of concrete structures using FRP rods was held in Tokyo by JSCE. The authors submitted a paper on transfer lengths of FRP rods as a problem of anchorage of pretensioned prestressed concrete structures. The paper included 14 types of FRP rods made from fibers of carbon, aramid, glass and vinylon. The past experiments were carried out on single specimen of each FRP rod. So, more experimental data are needed to conclude the exact transfer lengths of each FRP rod. The authors have continued this kind of research, that is "Transfer lengths" to accumulate more data. This present research was made on 12 types of FRP rods from the last year's list and focused on the comparative study between last and this year's one. In addition to transfer lengths of each FRP rod, this present paper includes also the transfer length occurring at cutting pretensioned precast concrete member off. And more the effective prestress of this kinds of structures was examined. Finally, the minimum cover thickness of concrete for FRP rods was examined experimentally.

2 TENSILE PROPERTIES OF FRP RODS

Table 1 shows the specification of FRP rods used in this experiment, including all type of FRP rod with the diameter of 7.5-8.0mm and different

Table 1 Specification of FRP rods

SYMBOL	φ mm	AREA cm²	FIBER TYPE	MATRIX MATERIAL	FIBER (%)	DEFORMATION TYPE
K-C2	8	0.502	CARBON (PAN)	EPOXY	61.7	SPIRAL
L-C2	8	0.502			50～60	ROUND&SPIRAL
T-C2	7.5	0.304			64	STRAND
K-CP	8	0.502		PPS	55	STONEGRAIN
S-A2	8	0.502	ARAMID	V.E.*	65	ROUND&SPIRAL
M-A2	8	0.500	ARAMID	EPOXY	65	BRAIDED
K-G2	8	0.502	E-CLASS		62.5	ROUND&SPIRAL
KR-V2	8	0.502	VINYLON		69.5	ROUND&TWIRL

* VINYL-ESTEROL

Table 2 Results of tensile test of FRP rods

ROD SYMBOL	TENSILE STRENGTH (kgf/cm²)		MODULUS OF ELASTICITY (x10⁶kgf/cm²)	
	MAKER AVE.	MEAS. AVE.	MAKER AVE.	MEAS. AVE.
K-C2	192	177	1.31	1.37
L-C2	180	137	1.30	1.60
T-C2	213	218	1.47	1.31
K-CP	175	164	1.44	1.29
S-A2	193	178	0.54	0.50
M-A2	130	151	0.66	0.61
K-G2	126	135	0.47	0.45
KR-V2	80	69	0.22	0.25

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surface conditions, composed of carbon, aramid, glass and vinylon fiber.

Table 2 shows the results of the tensile test obtained in 1991. The measured values denote the average ones among 3-20 test pieces per FRP rod. And measured values were adopted at analyzing of transfer lengths and effective prestress later.

3. TRANSFER LENGTH OF FRP RODS

3.1 OUTLINE OF EXPERIMENT

The specimen having 10cm square and 180 cm long is shown in Fig.1. The FRP rod was placed at the center longitudinally before concreting in the steel form work. A total of 11 specimen were made from four types of fibers. They are shown in Table 1. The specimens were fabricated by using the pretensioning bench with hydraulic jacks for tensioning the rods and steel form work for concreting. The tension applied to FRP rods were 50%, 60% and 70% of the makers tensile strength. Concreting was made after FRP rods were tensioned. The design compressive strength of concrete was approximately 450 kgf/cm^2. The prestressing to specimen were made after six days of curing.

To measure the amount of prestress introduced to the specimen, 30mm strain gauges were fixed axially on the concrete surface and the corresponding strains were measured. The location of gauges are also shown in Fig. 1. After the prestressing, the strains were measured for two week continuously and recorded the strain distribution data. After the strain measurements, the specimen were kept for a few months and then static bending test were executed. The loading system for static bending test is shown in Fig. 2.

After the static bending test, a cut-off test was carried out to investigate the transfer length of precast concrete members using FRP rod. The location of strain gauges at cut-off test is shown in Fig. 3.

The typical example of mix design and mechanical properties of concrete are shown in Table 3 and 4. In these tables, group I and group II show the data of 1991 and 1992 respectively.

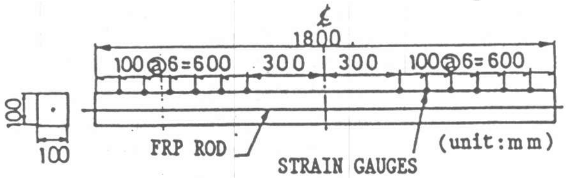


Fig.1 Transfer length test specimen and location of strain gauges

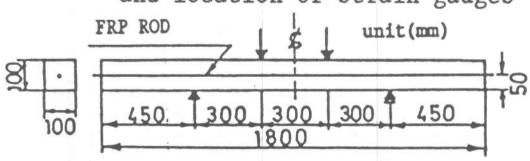


Fig.2 Static bending test specimen

Table 4 Mechanical properties of concrete

GROUP	COMPRESSIVE STRENGTH (kgf/cm²)	TENSILE STRENGTH (kgf/cm²)	MODULUS OF ELASTICITY (kgf/cm²)
I	484	33.2	2.46*10E5
II	427	28.4	2.69*10E5

Table 3 Mix design of concrete

GROUP	W/C (%)	S/a (%)	SLUMP cm	AIR (%)	UNIT WEIGHT (kgf/cu.m) W	C	S	G(S)	G(L)
I	40	37	11.8	2	220	550	539	388	582
II	39	37	9.1	1.2	215	550	565	384	563

I:1991. II:1992

3.2 ESTIMATION OF TRANSFER LENGTH

To relatively-estimate the transfer length of FRP rods with respect to the type of fibers and not by the size, the following assumptions were made previously. To state this estimation briefly;

a) the strain at the center of each specimen was estimated from the approximate strain distribution curve (ref. to Fig.4).
b) the ratio of measured strain from one end (ε) and the calculated strain at center (ε_c) was calculated as none-dimensional figure.
c) the ratio of (l/ϕ) was determined by the distance of position of strain gauges l and the diameter of FRP rods ϕ.
d) the (σ / σ_c)Vs (l/ϕ) was plotted and all the points were joined by a straight line, where (σ / σ_c) is equivalent to ($\varepsilon / \varepsilon_c$).
e) from the above non-dimensional distribution curve, the transfer length was determined when prestress level became constant.

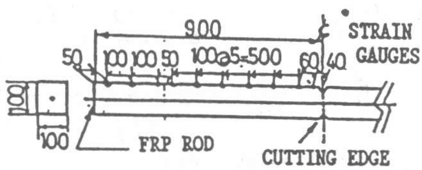


Fig. 3 Location of strain gauges at cut-off test

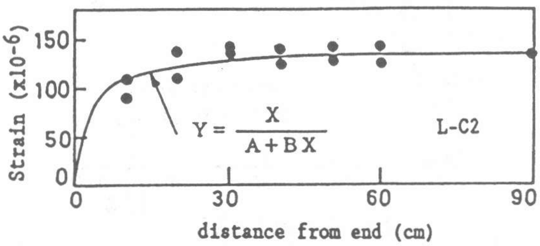


Fig. 4 Typical strain distribution on specimen

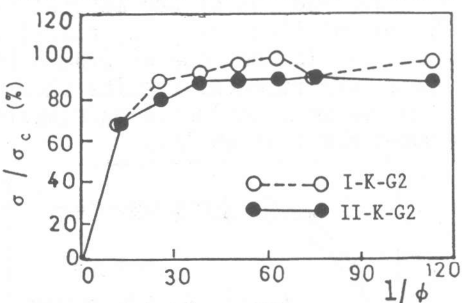
3.3 TRANSFER LENGTH IMMEDIATELY AFTER PRESTRESSING

Figures 5(a) to (e) show the stress ratio versus transfer length(l)/diameter(ϕ) curves of FRP rods. The black dot and straight line show the present year data while the white circle and dotted line denote the data of previous year. Figure 5(a) is on glass FRP rod, 5(b) & (c) are on carbon FRP rods and (d) &(e) are on aramid FRP rods. From the figures, the observed data showed that the general nature of curves agreed well between the data of 1991 and 1992 as far as the transfer length was concern. The present values of stress ratios are found to be slightly lower than the previous year. But in the carbon FRP rods the the stress ratios are almost the same for both years.

Table 5 Transfer length due to deformation condition

SURFACE CONDITION	FIBER	SYMBOL	Dia. ϕ(cm)	*l/ϕ (1991)	*l/ϕ (1992)
STRAND	CARBON	T-C2	7.5	53.3	53.3
BRAIDED	ARAMID	M-A2	8	50	50
SPIRAL	CARBON	K-C2	8	37.5	---
TWIRL		L-C2	8	37.5	37.5
GRAINED		K-CP	8	37.5	---
HALF SPIRAL	ARAMID	S-A2	8	62.7	62.7
SPIRAL	GLASS	K-G2	8	62.5	62.5
TWIRL	VINYLON	KR-V2	8	---	---

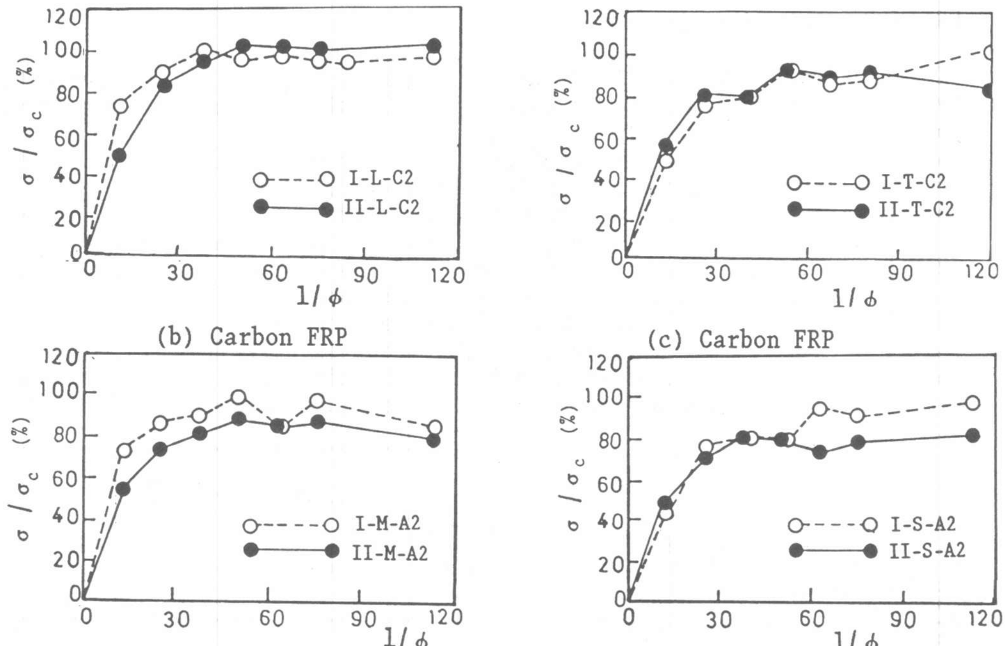
*Prestressing level is at 60% of tensile strength



(a) Glass FRP

Fig.5 Stress ratio Vs l/ϕ ratio curves

The transfer length of FRP rods immediately after the prestressing were grouped and tabulated according to the surface conditions as shown in Table 5. From the table, the comparison between the present and previous



(b) Carbon FRP (c) Carbon FRP

(d) Aramid FRP (e) Aramid FRP

Fig. 5 Stress ratio Vs. 1/ϕ ratio curves

data was made. The transfer length to diameter of FRP rod (1/ϕ) of carbon FRP strands had the same value of 53.3, the braided aramid FRP rod had 1/ϕ of 50 and twirl carbon rod showed 1/ϕ of 37.5. The same values were obtained with the half-spiral aramid FRP rod and spiral glass FRP rod as 1/ϕ of 62.7 and 62.5 respectively. Observing the experimental results, it was found that there is a conformity between both previous and present year.

3.4 TRANSFER LENGTH DUE TO DIFFERENT PRESTRESSING LEVELS

Figures 6 (a) & (b) showed prestress ratio versus distance/diameter ratio curve of aramid and carbon FRP rods. The level of prestressing were 50%, 60% and 70% of the makers' tensile strength. The nature of each curves showed similarity. The transfer length to diameter of FRP rod ratio is about 50 in the case of aramid FRP rods and 53.3 in carbon FRP rods. The above experimental results showed that the prestressing level difference have minimum influence on transfer lengths of carbon FRP rods (T-C2) and aramid FRP rods (M-A2).

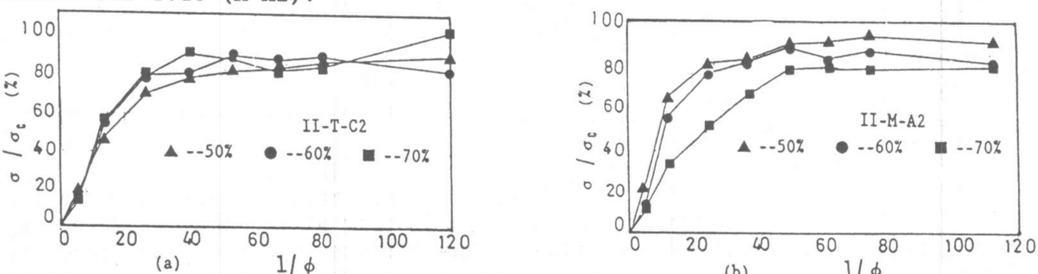


Fig. 6 Stress Vs. 1/ϕ at varying prestressing levels

3.5 TRANSFER LENGTH AT CUTTING-OFF

Figures 7 (a) to (c) shows the strain distribution axially on the specimen after cutting off. They are grouped in carbon, glass, and aramid. From Fig. 7(a) the carbon FRP rods were almost identical to each other. But in glass FRP rods the strains readings nearest to the cutting edge showed positive strains which means some slippage might occur. The other strain gauge points were stable with no changes, showing sufficient bonding.

In the case of aramid FRP rods, the present data showed positive strains at ends, this was also the indication of possibility of end slippage. Overall performances of the transfer length of FRP rods in cutting-off test showed encouraging results.

The transfer length according to the fiber group at cutting off were found to be, 18-20 ϕ for carbon fibers, 23 ϕ for glass fiber and 25-32 ϕ for aramid fibers. Totally it is recommended that, transfer length at cutting off is enough, taking about 30cm.

Table 6 Effective prestress

SYMBOL	STRESS LEVEL xPu	PRESTRESS(kgf/cm²) MEASURED ①	CALCULATED ②	RATIO (%) ①/②
I-K-C2	0.6	47	54.5	86
I-L-C2	0.6	31	41.6	75
II-L-C2	0.6	35.9	42.1	85
I-T-C2	0.6	23	33.8	68
II-T-C2	0.6	33.7	39.4	85
II-T-C2	0.5	27	33.5	80
II-T-C2	0.7	37.1	45.8	81
I-K-CP	0.6	44.1	48.8	90
I-S-A2	0.6	51	57.7	88
II-S-A2	0.6	35.9	45.3	79
I-M-A2	0.6	41	49.5	83
II-M-A2	0.6	37.42	48.25	77
II-M-A2	0.5	26.95	36.09	75
II-M-A2	0.7	42.92	52.27	82
I-K-G2	0.6	35	40.1	87
II-K-G2	0.6	27.12	34.6	78
II-K-G2	0.5	27.12	30.82	87
II-KR-V2	0.6	*	19.19	*

note:
① measured value from re-cracking moment by elastic theory
② initial prestress after two weeks

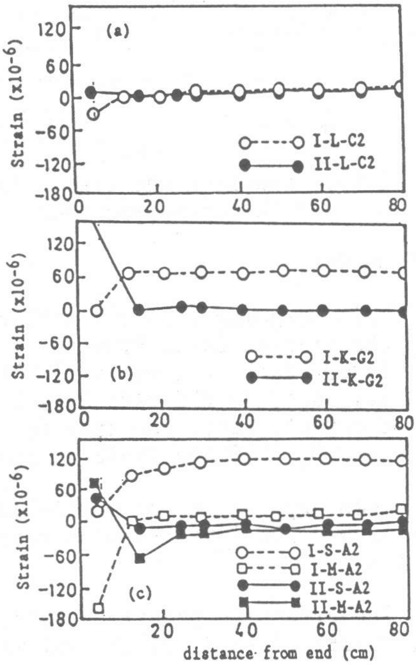


Fig. 7 Cut-off test results

4. EFFECTIVE PRESTRESS EVALUATION

The effective prestress measured on specimen was determined from the static bending test. The calculated prestress for previous year, included the prestress loss up to one week but for the present year, the prestress loss were measured up to two weeks. The present data for two week included, some losses due to elastic shortening, relaxation, creep and shrinkage. The measured and calculated values are shown in Table 6. From the table around 75% to 90% of the introduced prestress retained on the carbon FRP rods, 79% to 88% retained on aramid FRP rods and 78% to 87% on glass FRP rods. Totally, the mean value of effective prestress was 80% as far as FRP rods used here were concerned.

5. COVER THICKNESS FOR FRP ROD

The minimum cover thickness test of pretensioned concrete structures using FRP rods were conducted on vinylon,carbon, aramid and glass fibers of 8mm diameter. The specimen were 10cm square and 60cm long with each FRP rod placed with 5mm, 10mm and 15mm cover of concrete. The cross-section and cracks on the surface of the sample specimen is shown in Fig.8. All the cracks on the specimen are in the longitudinal direction. The pretensioning, placing and procedure for this test was also the same to that of transfer length. The prestressing level for vinylon, aramid and carbon was 60% of the tensile strength. For the glass FRP rods, the prestressing level was 50% of the tensile strength. The cracking and non-cracking with respect to FRP rods are shown in Table 7. The minimum cover thickness may be recommended as 10mm vinylon, 15mm for carbon, but glass and aramid FRP rods might be more than 15mm.

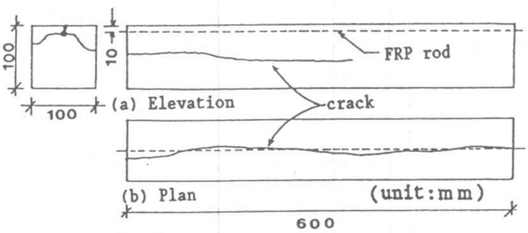


Fig. 8 Test specimen and cracks in cover thickness specimen

Table 7 Minimum cover thickness of FRP rods

ROD SYMBOL	COVER THICKNESS		
	5mm	10mm	15mm
II-KR-V2	crack	no crack	no crack
II-K-G2	crack	crack	crack
II-M-A2	crack	crack	crack
II-L-C2	crack	crack	no crack

6. CONCLUSIONS

This on-going research utilized previous data and comparison was made with the present data. From the experiment it was found that the former and the later data agreed well. The deformations and different types of material used in FRP rods have minimal influence on the transfer lengths. In the cut-off test, the transfer lengths of carbon, glass and aramid rods are 18-20 Ø, 23 Ø and 25-32 Ø, respectively.

Some experiments on multi-level prestressing to aramid and carbon FRP rods showed the level of prestressing had minimum influence to the transfer lengths.

The effective prestress retained on carbon, aramid and glass were 75-90%, 79-88% ,78-87% of the initial prestress, respectively.

The minimum cover thickness of concrete required were obtained experimentally for vinylon, glass, aramid and carbon FRP rods.

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References:

S. Matsumoto et al. Experimental Studies on Transfer Lengths of FRP Rods. JSCE. 1992, Conc. Tech. pp. 235-240