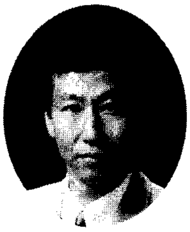
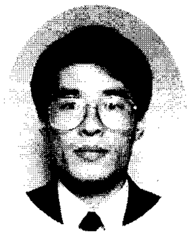
Effects of Stressed and Unstressed Reinforcements on Prestressed Concrete Members with Unbonded Tendons



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ABSTRACT

The research purpose of this paper is to investigate the influential parameters on the unbonded tendon stress. The parameters were the reinforcing ratio, the prestressing ratio, and the loading type. To this end, first, the influence of parameters were examined with twenty eight test results obtained from references. Then, an experimental study was carried out with nine specimens. Test variables were the reinforcing ratio and the prestressing ratio. Specimens were divided equally into three groups and each group had a different level of the reinforcing ratio. Each specimen within a group has a different level of the prestressing ratio. The investigation with previous and current tests revealed the followings; (1) the length of crack distribution zone does not have a close relation with the length of plastic hinge, (2) the prestressing ratio does not affect both the length of crack distribution and the length of plastic hinge, (3) the tendon stress variation is in reverse relation with the ratios of mild steels and tendons, (4) the loading type may not affect significantly the length of crack distribution zone, (5) AASHTO LRFD Code equation and Moon/Lim's design equation predicted the test results well with some safety margins.

Keywords : unbonded tendon, reinforcing ratio, prestressing ratio, loading type, crack distribution zone, plastic hinge

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1. Introduction

The unbonded tendon stress has to be computed considering the average of concrete strains at the level of tendon. Thus, the curvature distribution over an entire beam length is one of the most important influential parameters on the unbonded tendon stress. The curvature, in turn, is influenced mostly by the prestressing level (or the amount of tendons), the amount of mild steels, and loading types.

A concrete beam post-tensioned with unbonded tendons should be provided with bonded mild steels in order to control flexural cracks. Mild steels as well as tendons affect the tendon stress at ultimate failure of a beam since they alter the equilibrium state at a cross section and, consequently, the depth of compression block and the curvature at the section.

The loading type is also one of influential parameter since it changes the moment distribution along beam length. A concentrated load makes a plastic hinge formed in a quite narrow region. However, an uniformly distributed load or third point loads develop the plastic hinge over a wide region. Since most of strain variations of concrete are concentrated on the plastic hinging zone, the loading type is an important parameter. However, Harajili et al^8 argued that the loading type did not affect the tendon stress. Thus the research on this matter is necessary.

The purpose of this study is to investigate the relations between the unbonded tendon stress and the influential parameters. To this end, first, influential parameters, such as amount of tendons, amount of mild steels, and loading types were examined with previous test data. Then, an experimental study was carried out with nine test specimens.

2. Investigation of Previous Test Data

The relation between the unbonded tendon stress and influential parameters was investigated with previous test data(1),(2). The results of investigation were illustrated in Fig. 1 and 2. The horizontal axes of figures represent the prestressing ratio(ρ_p), the reinforcing ratio(ρ), respectively. The vertical axes represent the measured length ratio of crack distribution zone to member length (L_c/L). The length of crack distribution zone was used to estimate the plastic hinge length because the length of plastic hinging zone cannot be measured accurately.

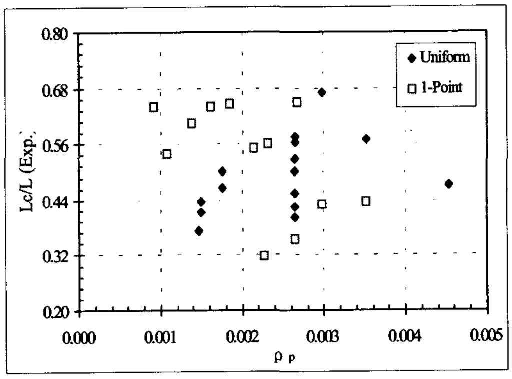

Fig. 1 Prestressing ratio ρ_p vs. length ratio of crack distribution zone

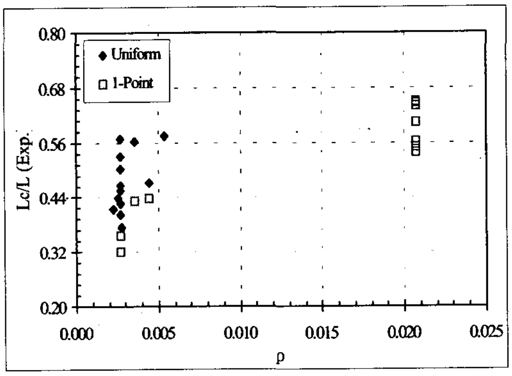

Fig. 2 Reinforcing ratio ρ vs. length ratio of crack distribution zone

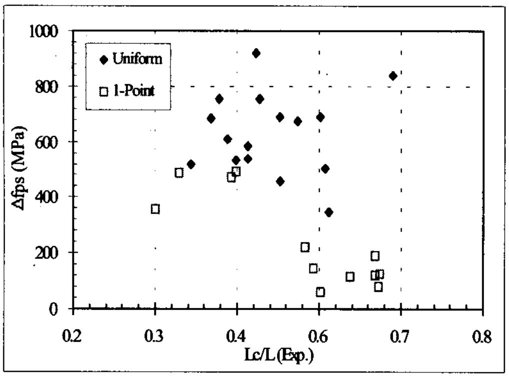

Fig. 3 Length ratio of crack distribution zone vs. tendon stress increase

The actual length of plastic hinge would be shorter than the length of crack distribution zone. Fig. 3 shows the relation between the crack distribution zone length and the tendon stress increase. All the data in Fig. 1 to 3 were divided into two groups according to the loading types.

No relations were found from Fig.1 which shows an influence of the prestressing ratio on the length of crack distribution zone. However, Fig, 2 shows that there is a relation between the length of crack distribution zone and the reinforcing ratio. As seen from Fig. 3, specimens subjected to a concentrated load showed that the crack distribution zone length has a reverse relation with the increase of tendon stress. Theoretically, however, the tendon stress increase is proportional to the length increase of plastic hinging zone which seems to be related with the length of crack distribution zone. But no such trend was found from specimens subjected to uniform or third-point loads.

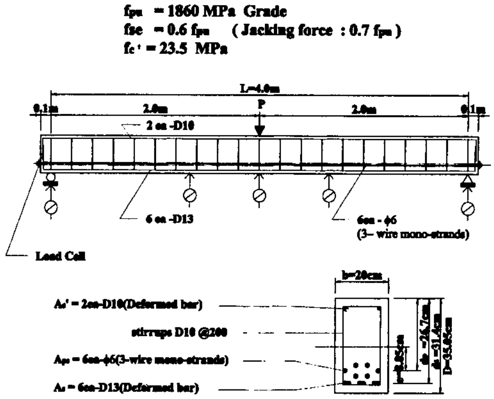

Fig. 4 Typical specimen

Table 1 Specimen lists

Specimen	bxD (cm)	L (cm)	Loading type	f_{se} (MPa)	f_c' (MPa)	A_{ps} (ρ_p)	A_s (ρ)	A_s' (ρ')	d_p (cm)	d_s (cm)	e (cm)	L/d_p
J-1	20x35.05	400	1-point	$0.6f_{pu}$	34.34	2-Φ6 (0.00074)	2-D13 (0.004)	2-D10 (0.0023)	26.7	31.4	4.06	15
J-2						4-Φ6 (0.00148)						
J-3						6-Φ6 (0.00223)						
K-1						2-Φ6 (0.00074)	4-D13 (0.008)					
K-2						4-Φ6 (0.00148)						
K-3						6-Φ6 (0.00223)						
L-1						2-Φ6 (0.00074)	6-D13 (0.012)					
L-2						4-Φ6 (0.00148)						
L-3						6-Φ6 (0.00223)						

*NOTE : straight tendon profile
f_{pu} =1860 MPa Grade
Φ6 = 0.1982㎠ (3-wire mono-strand)
f_y =420 MPa Grade

Table 2 Test results

Specimen	f_{se}(Mpa)	f_{ps}(Mpa)	Δf_{ps}(Mpa)	P_{cr}(kN)	P_{max}(kN)	P_{max}/P_{cr}	δ_{max}(mm)	L_c(mm)
J-1	1878.26	1116.14	762.12	22.38	54.08	2.42	97.2	164
J-2	1759.22	1113.67	645.56	30.62	71.85	2.35	94.0	167
J-3	1524.18	1118.62	405.56	36.28	73.03	2.01	43.2	141
K-1	1794.49	1118.12	676.37	24.12	79.41	3.29	74.8	241
K-2	1748.40	1116.64	631.76	29.81	92.95	3.12	90.6	224
K-3	1515.21	1119.24	395.97	38.54	102.57	2.66	39.8	179
L-1	1752.54	1116.64	635.90	32.85	103.94	3.16	71.0	264
L-2	1549.11	1115.65	433.46	35.01	110.81	3.17	47.0	262
L-3	1515.51	1117.13	398.38	39.22	129.66	3.31	40.0	267

f_{se} : Effective Prestress/1ea
f_{ps} : Ultimate Tendon Stress/1ea
Δf_{ps} : Tendon Stress Increase/1ea
P_{max} : Maximum Load
P_{cr} : Initial Cracking Load
δ_{max} : Maximum Deflection
L_c : Length of crack distribution zone

3. Experimental Study

The investigation of previous test data did not show clear relations among the prestressing ratio, the reinforcing ratio, the length of crack distribution, and the tendon stress variation.

Thus, an experimental program was planned to examine their relations. A total of 9 specimens listed in table 1 was divided into three groups called J, K, and L series, respectively. Specimens were divided equally into three groups and each group had a different level of the reinforcing ratio. Each specimen within a group have a different level of the prestressing ratio. No other parameters were applied in order to examine individual effects on measured length ratio of crack distribution zone to member length (L_c/L).

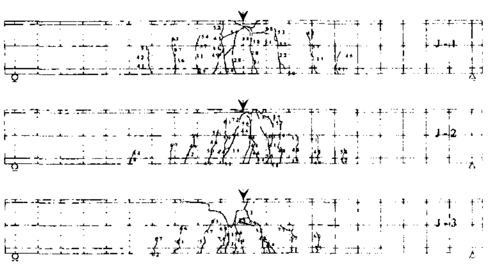

Fig. 5(a) Crack distributions of J-series

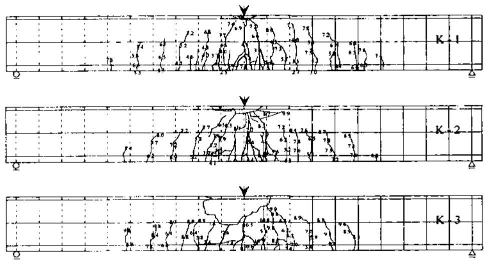

Fig. 5(b) Crack distributions of K-series

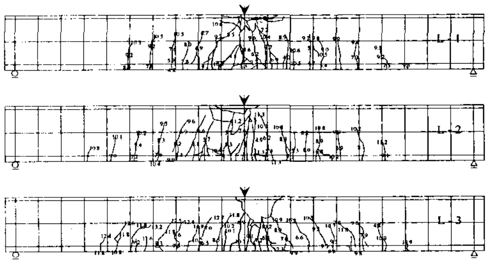

Fig. 5(c) Crack distributions of L-series

A concentrated load was applied to all the specimens. A typical test specimen is shown in Fig. 4. Test results were summarized in table 2 and the crack distributions are shown in Fig. 5.

4. Test Results

4.1 Influence of reinforcing ratio

Fig. 6 and 7 show the influence of mild steels on the length of crack distribution zone and the increase of tendon stress.

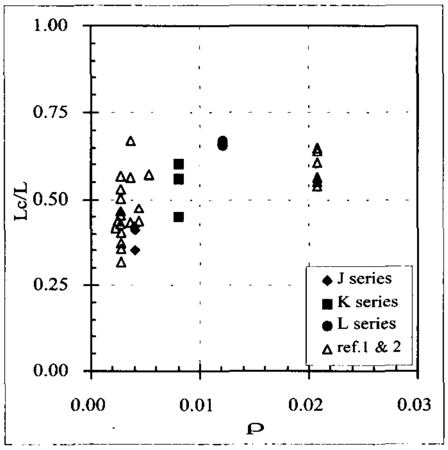

Fig. 6 Reinforcing ratio vs. length ratio of crack distribution zone

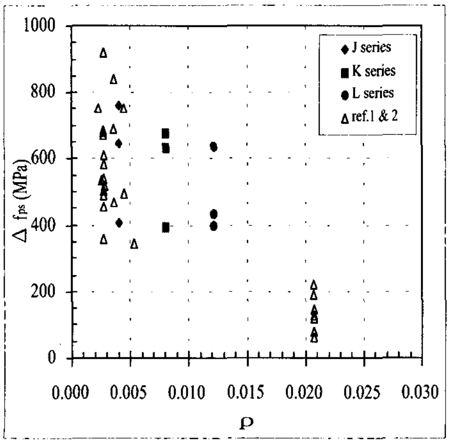

Fig. 7 Reinforcing ratio vs. Δf_{ps}

New test results were marked together with the previous test results in the same figure. As the reinforcing ratio increases, the length of crack distribution zone increases but the tendon stress decreases. It means that the reinforcing ratio is in reverse relation with the tendon stress variation. This is quite clear since mild steels alter the equilibrium equation on a cross section and, consequently, the depth of compression block and the curvature.

However, Fig. 6 shows that the length of crack distribution zone increases even though the tendon stress decreases with the increase of the reinforcing ratio. Thus, it can be concluded that the role of mild steels is to distribute cracks over a large area instead of increasing plastic hinge length. The length of crack distribution zone is not in a proportional relation with the plastic hinge length.

4.2 Influence of prestressing ratio

Fig. 8 and 9 show the influence of prestressing ratio on the length of crack distribution zone and the tendon stress increase. Even if the prestressing ratio increases, no close trends were found between the length of crack distribution zone and the

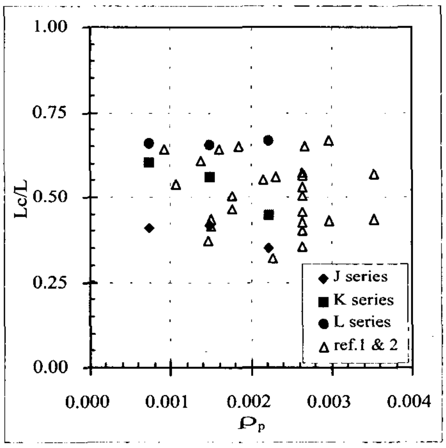

Fig. 8 Prestressing ratio vs. length of crack distribution zone

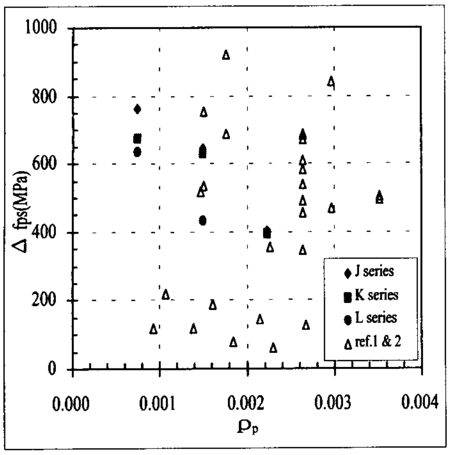

Fig. 9 Prestressing ratio vs. Δf_{ps}

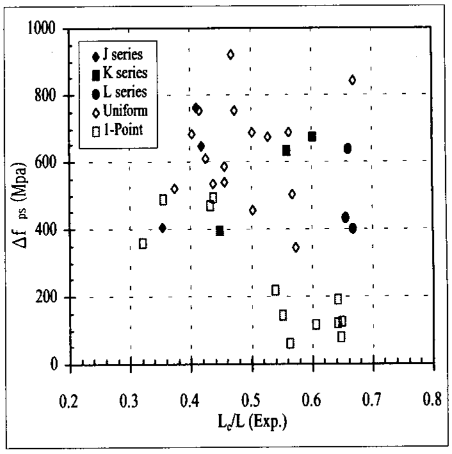

Fig. 10 Effects of loading types

tendon stress increase. However, it is interesting to find that the tendon stress is affected differently depending on the levels of the reinforcing ratio. Test results with low values of tendon stress increase in Fig. 9 were referred from the reference 2. The research purpose in reference 2 was to prove a possibility that the current ACI Code equation may overestimate tendon stresses if a large amount of mild steels is provided. Those test results obtained from eight specimens are shown in the bottom part of Fig. 9.

4.3 Influence of loading type

Although specimens in this study were subjected to a concentrated load at the midspan, the influence of loading type was examined comparing with previous test results (see Fig. 10). No close trends were found even with the addition of new test data to Fig. 3. Thus, further research is needed to evaluate the influence of loading type. However, it might be concluded for specimens subjected to a concentrated load that the length ratio of crack distribution zone is in reverse relation with the tendon stress variation.

4.4 Comparison with design'equations

Current test results together with those of reference 1 and 2 were compared with one analytical method and three design equations. The strain compatibility$^{(3)}$ method was used for analytical solutions. The design equations were ACI Code$^{(4)}$ equation(Eq. 1), AASHTO LRFD Code$^{(5)}$ equation(Eq. 2), and the design equation proposed by Moon and Lim (Eq. 3)$^{(3)}$.

$$f_{ps} = f_{se} + 69 + \frac{1.4 f_c'}{k \rho_p}$$
$$k = 100(L/d_p \le 35) \qquad (1)$$
$$k = 300(L/d_p \ge 35)$$

$$f_{ps} = f_{se} + \Omega_u E_{ps} \varepsilon_{cu} \left(\frac{d_p}{c} - 1 \right) \frac{L_1}{L_2}$$
$$f_{ps} \le 0.94 f_{py}$$
$$\Omega_u = \frac{1.5}{L/d_p} \ (1-\text{point loading}) \qquad (2)$$
$$\Omega_u = \frac{3.0}{L/d_p} \ (2-\text{point loading or uniform loading})$$

$$f_{ps} = 70 + 0.8 f_{se} + \frac{1}{15} \frac{(A_s' - A_s) f_y}{A_{ps}}$$
$$+ 6.5 \sqrt{\frac{d_s}{d_p} \frac{f_c'}{\rho_p} \left(\frac{1}{f} + \frac{d_p}{L} \right)} \qquad (3)$$
$$(f_{se} + 70 \le f_{ps} \le f_{py})$$

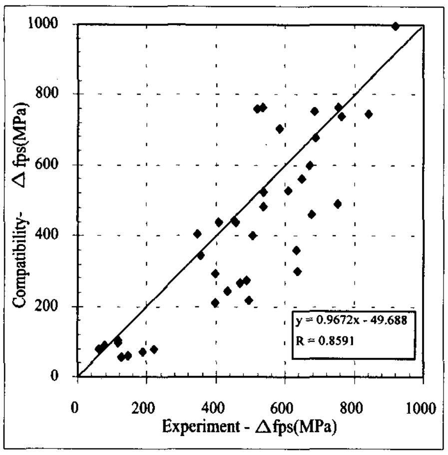

Fig. 11(a) Strain compatibility

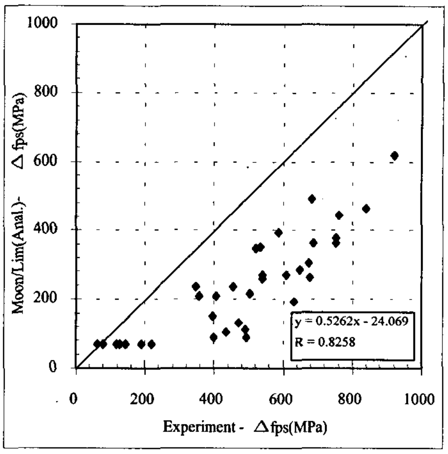

Fig. 11(c) Moon/Lim's equation

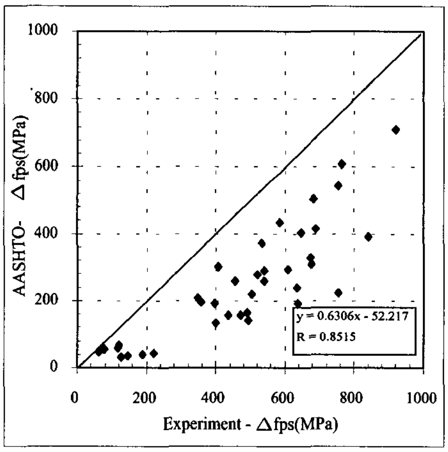

Fig. 11(b) AASHTO LRFD

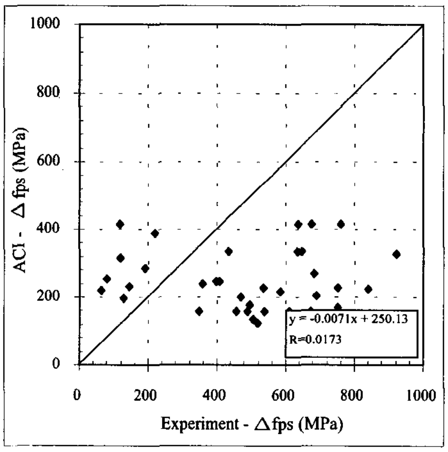

Fig. 11(d) ACI 318-95 Code

A good relation was obtained from the comparison with the strain compatibility method as shown in Fig. 11(a). The AASHTO LRFD Code equation and the proposed design equation also predicted the test results well with some safety margins(see Fig. 11(b) and (c)). However, the predicted tendon stresses by ACI Code equations deviated far from the test values.

5. Conclusions

(1) The prestressing ratio does not affect both the length of crack distribution and the length of plastic hinge significantly.

(2) The tendon stress variation is in reverse relation with the ratios of mild steels and tendons.

(3) The loading type does not affects the length of crack distribution zone.

(4) AASHTO LRFD Code equation and Moon/Lim's design equation predicted test results well with some safety margins.

Acknowledgement

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