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Study on Damage Controlled Precast-prestressed Concrete Structure with P/C MILD-PRESS-JOINT – Part 3: Experimental Study on Bond Behavior of EC Strands

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INTRODUCTION

The previous paper reveals the damage control effect and the mechanical characteristics of a frame with a PC Mild-Press-Joint method, through the partial frame experiments [1,2].
The elastic rotation of the joint occupied a large part of the deformation in the frame with PC Mild-Press-Joint. The elastic rotation of the joint was generated by bond slip of Epoxy resin Coated prestressing(EC) strands from the beam and column joint. (EC strands were rust-proofing prestressing strands coated with epoxy resin.) Accordingly, it is regarded as important to understand the bond behavior between EC strands and cement grout, in order to evaluate the hysteresis characteristics of the frame.
In the past research [3,4], it have been shown that the bond behavior of such a prestressing strand differs from that of a prestressing deformed bar. However, the bond behavior of prestressing strands have not been suggested on influence due to the various factors; for example, number of strands, and so on compressive strength of cement grout.
The aim of this paper is below:
1) To clarify the bond behavior between two or more EC strands and cement grout in the steel sheath through the pullout tests.
2) To propose a prediction method for the tension force (P) - displacement (δ) relation by modeling the bond behavior between two or more EC strands and cement grout.

Keywords: P/C MILD-PRESS-JOINT, PC strand, cement grout, bond behavior, epoxy resin coating

OUTLINE OF PULLOUT TESTS

Specimens

A pullout test was conducted to clarify the bond behavior between two or more EC strands and cement grout in the steel sheath. Fig. 1 shows specimens, load system and measurement method. Table. 1 lists test parameters and specimens. The specimen configurations and bar arrangement were the same as beam members at the partial frame examination (┼ -PC42-N-90) in Part 2. It was simulates the tension force and bond slip of EC strands at the joint of beam member(PC Mild-Press-Joint). On an each beam specimen, one (10-strands specimen only) or two steel sheaths were placed, and prestressting strands were set through the

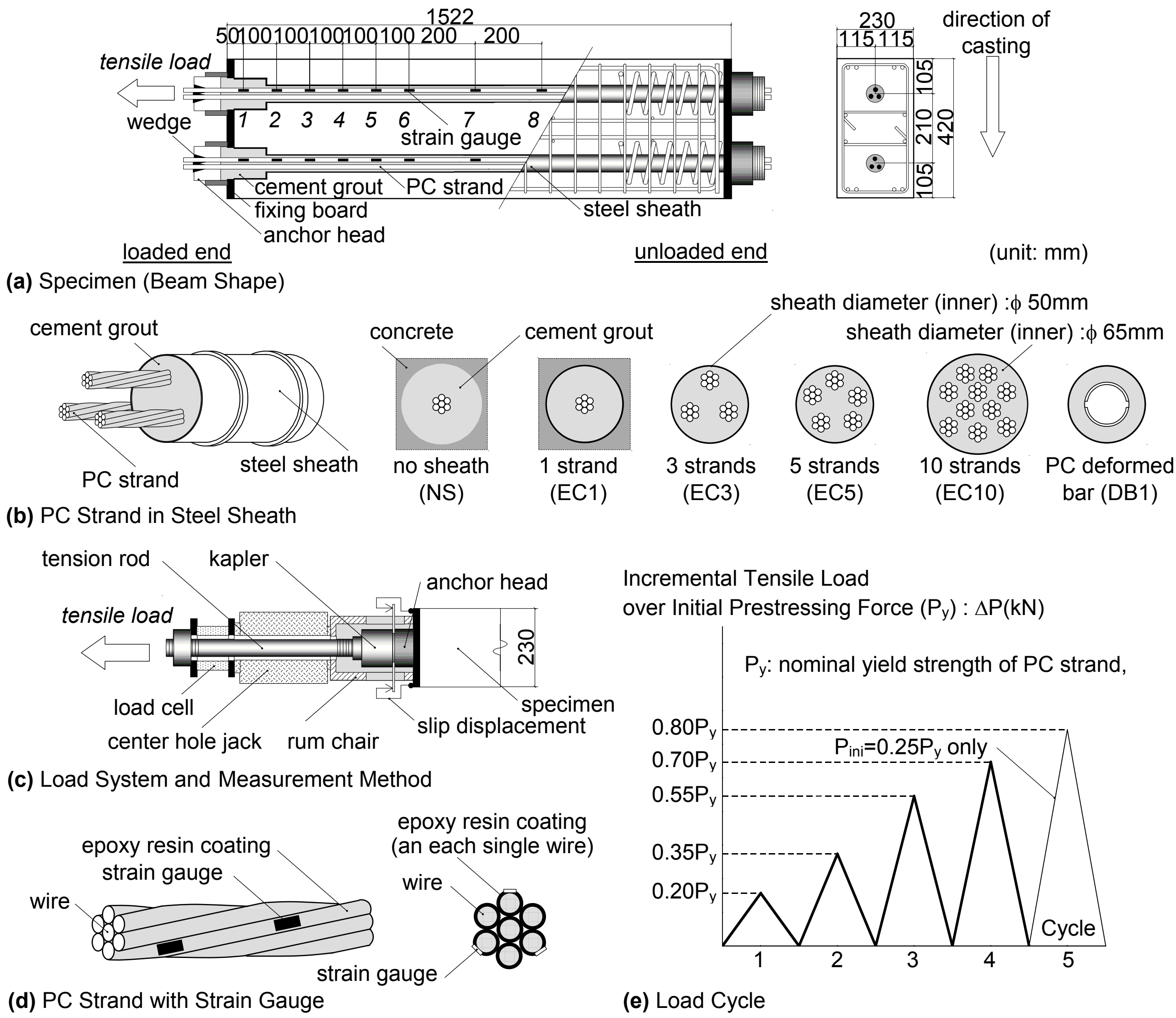


Fig. 1. Specimens, Load System and Measurement Method

steel sheath. After strand was prestrssed, cement grout was filled up with in the sheath. The total numbers of 9 beam specimens were made, and the total of 16 tests were carried out independently for each sheath. In addition, concrete design strength ($_cF_c$ = 90N/mm^2) was the same with all specimens.

The parameters of this test were as follows;

1) surface form of prestressing steel : EC strands (EC) or prestressing deformed bar (DB),
2) initial prestressing force of EC strands : 0.25P_y/strand or 0.5P_y/strand,
3) with or without epoxy resin coating : with (EC) or without (NC),
4) with or without steel sheath : with (SS) or without (NS),
5) cement grout compressive strength : $_G\sigma_B$ = 20, 40, or 90N/mm^2 level,
6) number of EC strands arranged in a steel sheath : 1, 3, 5, or 10 strands.

The last parameter was aimed at considering the setting method of bond periphery of EC strands surface (ϕ) in the case two or more EC strands are arranged in a steel sheath.

All prestressing strands used was formed by seven wires (SWPR7B), and the nominal diameter of the starand is 12.7mm. In an epoxy resin coated prestressing strand (EC strand), an each single wire was coated with epoxy resin.

A prestressing deformed bar was screw shaped bar whose diameter was 26mm. In a prestressing deformed bar specimens, since the initial prestressing force (P_{ini}) have little effect on bond behavior of the surface, it was not introduced (P_{ini}=0.0P_y).

Except for 10-strands specimen, the diameter of steel sheaths was 50mm, and that was 65mm in the case of 10-strands specimen. In the specimens without sheath (NS), the steel sheaths were removed after concrete

Tab. 1. Test Parameters and Specimens

spesimen *1	prestressing steel: tendon [diameter] (mm) *2	prestressing steel: strand yield strength $_p\sigma_{0.2\%}$*3 (N/mm^2)	prestressing steel: young's modulus $_pE_{exp}$ (kN/mm^2)	prestressing steel: initial prestressing force P_{ini}*4 (per strand)	cement grout: compressive strength $_G\sigma_B$ (N/mm^2)	cement grout: young's modulus $_GE$*5 (kN/mm^2)	cement grout: expansion ratio (%)	steel sheath *6
NC3-40-SS-25	3-NC[φ12.7]	1642	214	0.25P_y	78	22.8	0.0	○ (SS)
NC3-40-SS-50				0.50P_y	45	-	0.0	
SC3-40-SS-25	3-EC[φ12.7]			0.25P_y	78	22.8	0.0	
SC3-40-SS-50				0.50P_y	45	-	0.0	
SC1-90-SS-25	1-EC[φ12.7]	1631	212	0.25P_y	92	22.7	0.0	○ (SS)
SC3-90-SS-25	3-EC[φ12.7]				92	22.7	0.0	
SC5-90-SS-25	5-EC[φ12.7]				92	22.7	0.0	
SC5-40-SS-25		1692	216		42	-	0.0	
SC5-20-SS-25					20	-	7.4	
SC10-90-SS-25	10-EC[φ12.7]				72	24.7	0.0	
SC10-40-SS-25					44	-	0.0	
SC1-90-NS-25	1-EC[φ12.7]	1631	212	0.25P_y	92	22.7	0.0	× (NS)
SC3-90-NS-25	3-EC[φ12.7]				92	22.7	0.0	
SC5-90-NS-25	5-EC[φ12.7]				92	22.7	0.0	
DB1-90-SS-00	1-DB[D26]	1055	225	0.0	92	22.7	0.0	○ (SS)
DB1-90-NS-00					92	22.7	0.0	×(NS)

notes:
*1, specimen cross-section: 230×420(mm), length:1522(mm). *2, **NC**: no epoxy resin coated PC strand(φ12.7), **EC**: epoxy resin coated PC strand(φ12.7), **DB**: PC deformed bar(D26). cross-section (a_p, φ12.7: 98.71(mm^2), D26:548(mm^2)). *3, 0.2%offset. *4, $\mathbf{P_y}$: nominal yield strength of PC strand (=156kN).
*5, **-** : test results had a large dispersion. *6, **SS**: with steel sheath, **NS**: without sheath.

hardening. The expansion ratio of cement grout was 0.0% in cement grout compressive strength $_G\sigma_B$ = 40, 90N/mm^2 level, to having been 7.4% in $_G\sigma_B$ = 20 N/mm^2 level.

Load System

Fig. 1(c) shows load system. The tension rod was connected to the anchor head at the loaded end using the kapler. The tension rod was loaded tension force by the center hole hydraulic jack. The jack was supported to beam specimen through the rum chair. In this system, a whole bunch of EC strands was pulled out by an anchor head. Moreover, in a prestressing deformed bar specimens, a prestressing deformed bar was loaded tension force directly by center hole hydraulic jack.
Fig. 1(e) shows load cycle. The pullout test was conducted under one direction (tensile direction) cyclic load. The peak loads were controlled by incremental tension force (ΔP),and the incremental tension force (ΔP) was a value of over the initial prestressing force (P_{ini}).

Measurement Method

The tensile load (P) was measured using the center hall load cell. The bond slip displacement (δ) was realized by the two inductive displacement measurement as the relativity displacements between an anchor head and a fixing board. Strains of EC strand (ε) were measured at intervals of 100mm or 200mm from loaded end by strain gauge (Fig. 1(a)). The tequnique of adhesive the strain gauge was as follow: After epoxy resin coating had been removed from wire locally, and the strain gauge was adhered to it. The direction of strain gauge was the same as slanting of a wire,as shown in Fig. 1(d)). And, waterproofing care was used as the smallest possible. In addition, Young's modulus for prestressing strand ($_pE_{exp}$) were calculated from the strain measured by the same method.

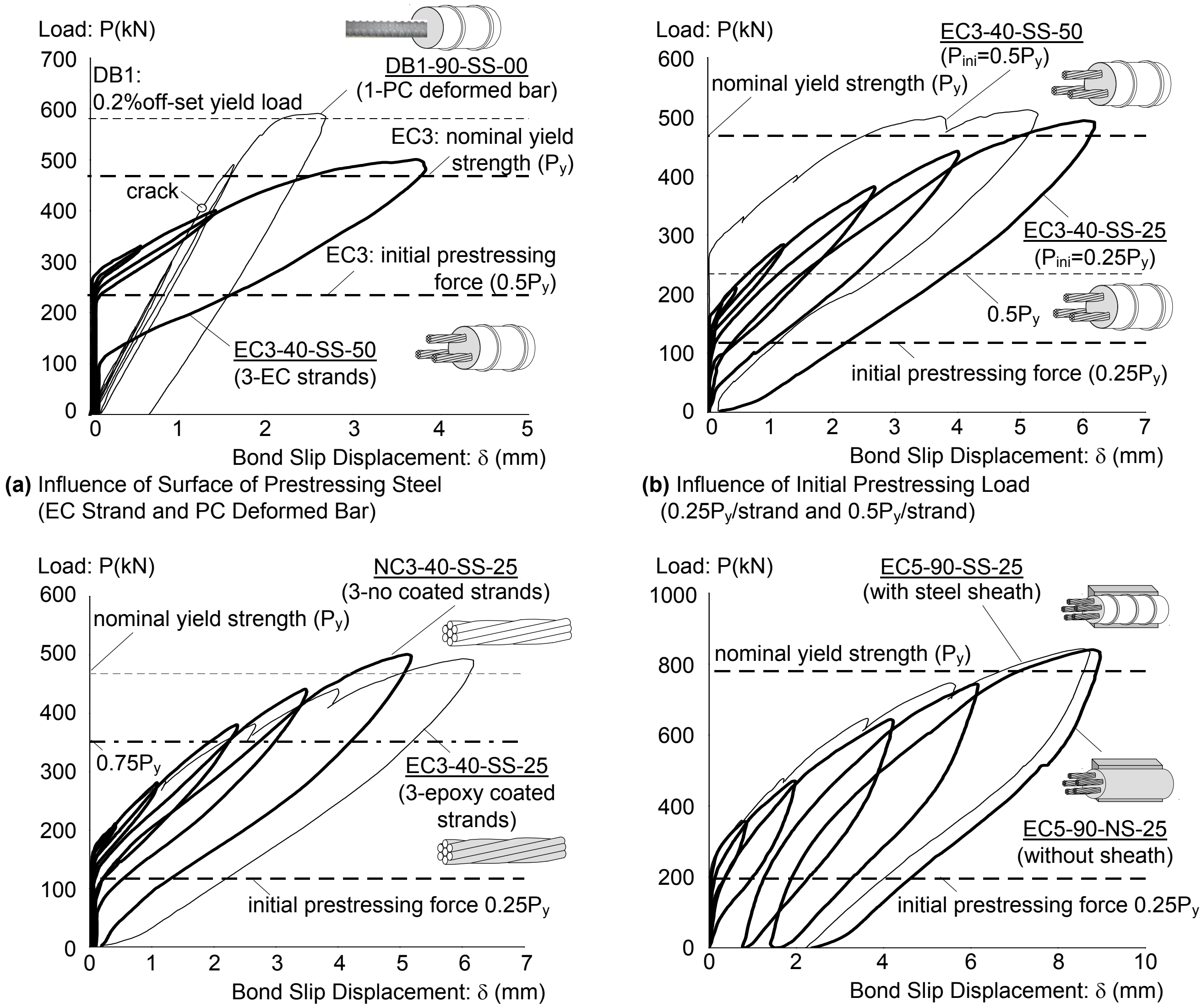
TEST RESULTS

Load (P)-Slip Displacement (δ) Relationship

Fig. 2 shows load (P) - bond slip displacement (δ) relations. Fig.2 shows the typical result of each parameter.

Influence of the Surface Form of Prestressing Steel (effect on damage control)

Fig. 2(a) shows P-δ relation of EC strand and prestressing deformed bar. The bond slip of EC strand (EC) occurred when the load reached initial prestressing force (P_{ini}). Thus, the anchor head began to separate from the fixing board on beam specimen. After EC strand began to slip, the stiffness of EC strand was close to linear. Then, the stiffness decreased gradually as the load neard the yield load(P_y). The residual slip displacement was extremely small owning to the initial prestressing force.
On the other hand, the initial stiffness of a prestressing deformed bar specimen (DB1) indicated almost linear up to P = 400kN. Then, the stiffness decreased because of the cracking on the specimen surface. The direction of crack observed on specimen was the same as the direction of sheath. In the yield load level of prestressing deformed bar, the width of crack became large.



(a) Influence of Surface of Prestressing Steel (EC Strand and PC Deformed Bar)

(b) Influence of Initial Prestressing Load ($0.25P_y$/strand and $0.5P_y$/strand)

(C) Influence of Epoxy Resin Coating (with or without Epoxy Resin Coating)

(d) Influence of Steel Sheath (with or without Steel Sheath)

Fig. 2. Load (P) - Bond Slip Displacement (δ) Relationship

To compare EC strand with prestressing deformed bar, the characteristic bond behavior of EC strands is acquired. The characteristic bond behavior is as follows: First, after EC strands began to slip, the stiffness of EC strand is smaller than that of PC deformed bar. This means that the bond slip displacement of EC strand is obtain easily. Second, The EC strand splits neither cement grout nor concrete. This means that the residual displacement of prestressing steel is more reducible. Therefore, using EC strand is effective in reduse the residual displacement of the frame.

Influence of Initial Prestressing Force

Fig. 2(b) shows the P-δ relation of high and low initial prestressing force tests. The illustration shows the case of 3-EC strands. In the high initial prestressing force test (P_{ini} = 0.5P_y/strand), only the envelope curve is shown. In the both tests, when the load reached each initial prestressing force (P_{ini}), the bond slip of EC strands occurred. Moreover, the both tests were the almost same character after EC strands began to bond slip until it reached the yield load level.Threfore, initial prestressing force dose not affect influence on P-δ relation, after EC strands began to slip until it reached the yield load level.

Effect of Epoxy Resin Coating

Fig. 2(c) shows the P-δ relation of tests with and without epoxy resin coating. The illustration shows the case of 3-prestressing strands. The bond slip displacement (δ) of test with epoxy resin coating (EC3) was larger than that of test without epoxy resin coating (NC3) a little. However, in the PC Mild-Press-Joint method, initial prestressing force was set to about 0.5P_y/strand. Furthermore, in the both tests, initial prestressing force was set to 0.25P_y/strand. Therefore, it is important to observe mainly about the load range from 0.25P_y/strand to 0.75P_y/strand.
Thus, when the load reached 0.25P_y/strand, no large difference was observed in bond slip displacement (δ). Moreover, when the load reached 0.75P_y/strand, the bond slip displacement (δ) of EC3 is larger at most about 10% than that of NC3 (EC3: 2.15 mm, NC3: 1.95mm).
Therefore, the epoxy resin coating have much little influence on the tension force (P) – bond slip displacement (δ) relation, as long as incremental load over initial prestressing force reaches 0.5P_y/strand.

Effect of Steel Sheath

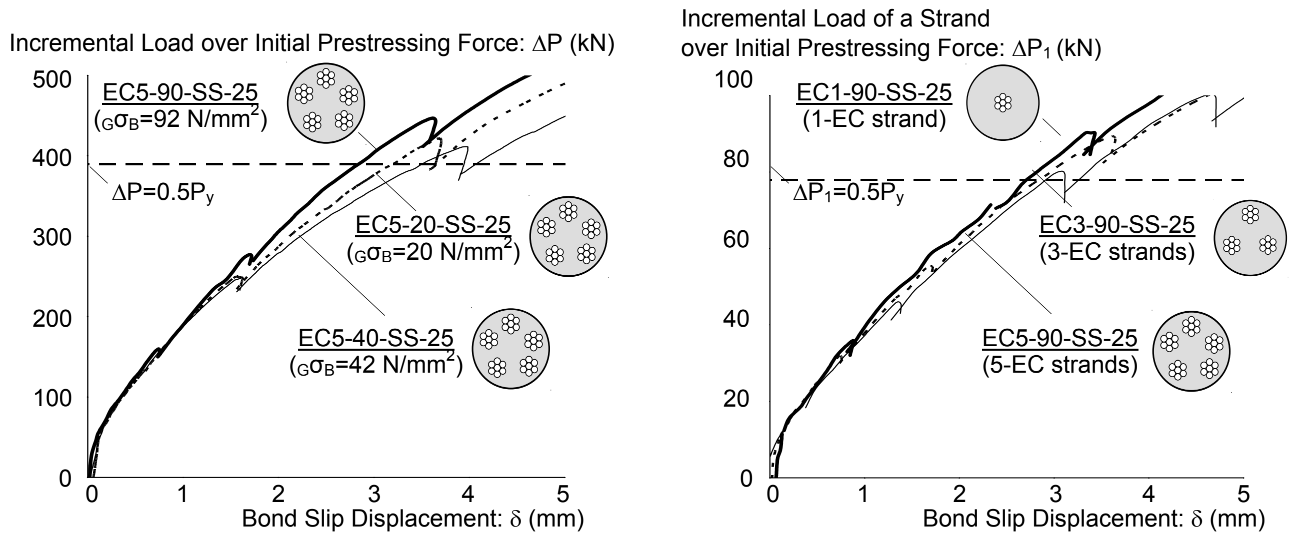
Fig. 2(d) shows the P-δ relation of tests with and without a steel sheath. The illustration shows the case of 5-EC strands. The both tests were the almost same character. Moreover, in the test without a sheath, the crack was not observed on the specimen surface. Therefore, The steel sheath have little effect on P-δ relation under the conditions cement grout compressive strength is 90N/mm^2.

Effect of Cement Grout Compressive Strength

Fig. 3(a) shows incremental load over initial prestressing force (ΔP) - bond slip displacement (δ) relation. The figure is shown about compressive strength of cement grout (${}_G\sigma_B$ = 20, 42 and 92N/mm^2) in the case of 5-EC strands. In the higher compressive strength of cement grout (${}_G\sigma_B$ = 92N/mm^2), the bond slip displacement (δ) was smaller than that in the others (${}_G\sigma_B$ = 20, 42N/mm^2) a little. Moreover, in the lower compressive strength of cement grout (${}_G\sigma_B$ = 20 N/mm^2), the bond slip displacement (δ) was smaller than that in the case of ${}_G\sigma_B$ = 42N/mm^2. Thus, some difference was obseved due to difference in cement grout compressive strength. However cement grout compressive strength have little influence on P-δ relation, as long as incremental load over initial prestressing force reaches 0.5P_y/strand.

Influence of Number of Strands

Fig. 3(b) shows incremental load of a single strand over initial prestressing force (ΔP_1) - bond slip displacement (δ) relation. The illustration shows about 1-, 3-, and 5-EC strands in the higher compressive strength of cement grout (${}_G\sigma_B$ = 90N/mm^2 level). ΔP_1 is calculated from dividing ΔP by the number of EC strands. The number of EC strands have little influence on ΔP_1-δ relation. (Although not shown in the figure, the same result as a figure was obtained also about the case of 5- and 10-EC strands in ${}_G\sigma_B$ = 42N/mm^2.)

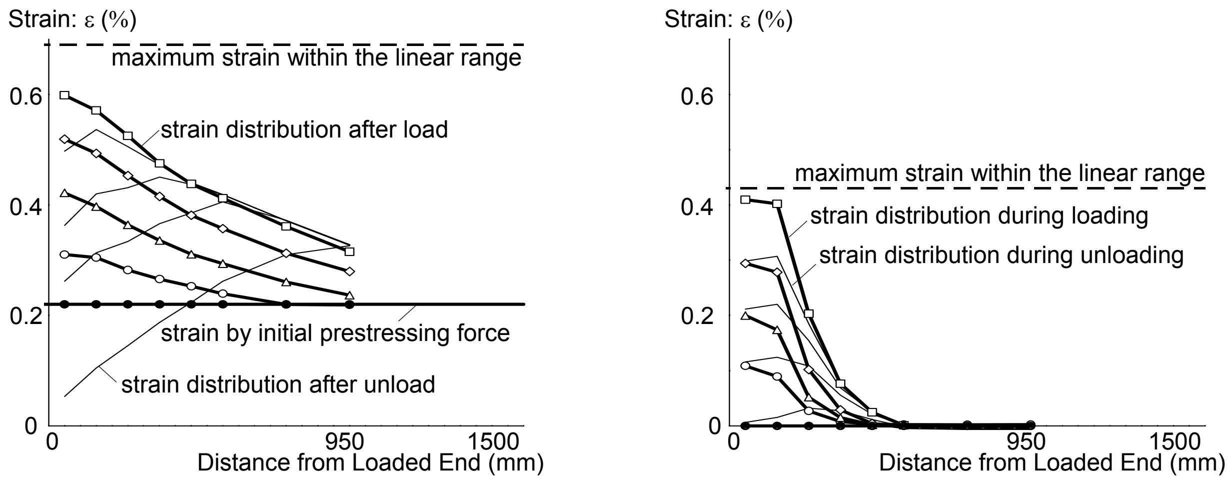


(a) Influence of Cement Grout Compressive Strength **(b)** Influence of Number of Strands in Steel Sheath

Fig. 3. Incremental Load over Initial Prestressing Force (ΔP) – Bond Slip Displacement (δ) Relationship

Strain Distribution

Fig. 4(a) shows the strain distribution of EC Strand specimen (EC1-90-NS-25). The thick line in the figure shows transition during loading. And the thin line shows that during unloading. Although it was loaded to a larger load level than that shown in the figure in this experiment, until strain within the elastic range of EC strand obtained are shown here. In addition, the strain by initial prestressing force (ε_{ini}) in Fig. 4(a) is average strain at an each measuring point before the test.



(a) 1-EC Strand (ϕ12.7) **(b)** 1-PC Deformed Bar (D26)

Fig. 4. Strain Distribution

As shown in Fig.4(a), the strain at loaded end increased gradually after the load reached initial prestressing force. The distributions of strain was almost linear, and the length of distribution (bond length) was about 800 to 900mm. The gradient of strain became large gradually with increasing load, and after incremental strain ($\Delta\varepsilon$) reached about 0.2%, it is admitted that the bond length became long. And also when $\Delta\varepsilon$ reached about 0.4% (equivalent to $\Delta P \approx 0.5P_y$), the gradient of strain distribution near the loaded end has change a little. Therefore, it is guessed that almost all bond failue of EC Strand has not occurred. In the case of unloading, the strain was decreasing gradually from the loaded end, and the bond stress occurred to the opposite

direction in the case of loading. Since the strain became smaller than ε_{ini} after unload, it seems to lost the prestressing force near the loaded end.
Fig. 4(b) shows the strain distribution of a prestressing deformed bar specimen (DB1-90-NS-00). In a prestressing deformed bar specimen, the bond length was about 400mm to 500mm. The gradient of strain distribution was tending to become large gradually, with increasing load. When incremental strain ($\Delta\varepsilon$) at the loaded end reached about 0.2%, the gradient of strain distribution near the loaded end was extremely small. Thus, it is admitted that bond failure of deformed bar has occurred.
The average bond strength of EC strands is smaller than that of prestressing deformed bar. The average bond stress of EC strand is almost constant throughout the bond length (transmission surface).Furthermore, in EC strand, bond failure did not observed, and the two value of maximum average bond stress was almost equal in loading and unloading. Thus, in EC strand tests it is guessed that frictional action predominates over the stress transfer mechanism between EC strands and the cement grout.
It is considered that this frictional action forms the bond behavior of EC strands do not damage cement grout greatly, this behavior can be called "the elasticity bond behavior ".

Bond Periphery of EC Strand Surface (ϕ) and Maximum Average Bond Strength (τ_{max})

Average bond strength (maximum average bond stress τ_{max}) required evaluating "the elasticity bond behavior" of EC strands, and bond periphery of prestressing strand surface (ϕ) which uses for calculating τ_{max} is considered. These are discussed from the average bond stress τ - ΔS relation. ΔS is the integration incremental strain $\Delta\varepsilon$ (after load reached initial prestressing force), and it is equivalent to slip displacement (δ) at the loaded end.

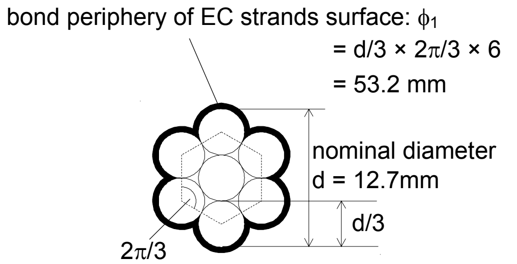


Fig. 5. Bond Periphery of 1-EC Strands Surface (ϕ_1)

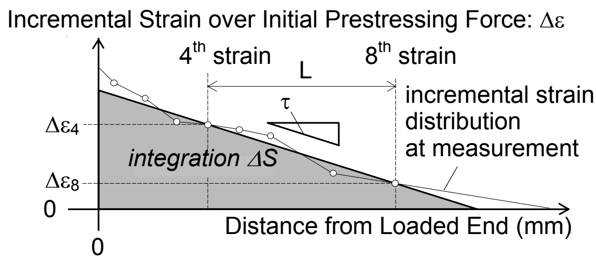


Fig. 6. Integration Method of Incremental Strain

Fig. 5 shows the calculation outline of the bond periphery of 1-EC strand surface (ϕ_1). It is considered that ϕ_1 is the whole periphery of an EC strand surface which touches cement grout. Here, it is assumed that ϕ of 3-, 5-, and 10-EC strands (ϕ_n) is calculated temporarily from multiplying ϕ_1 by the number of strands (n) simply. (It is not considered about the effect of a group). Moreover, average bond stress (τ) is the average stress of the section from the 4th to the 8th strain measuring point (Fig. 1(a)) which had little dispersion of strain, and it is calculated from equation (1).

$$\tau = \frac{(\Delta\varepsilon_4 - \Delta\varepsilon_8) \times {}_pE_{exp} \times a_p \times n}{L \times \phi_n} \qquad (1)$$

Where [$\Delta\varepsilon_4$, $\Delta\varepsilon_8$: Incremental strain of EC strands at the 4th, the 8th strain measuring point (Fig. 1(a)), ${}_pE_{exp}$: Young's modulus obtained from material testing (Table. 1), a_p: Nominal cross-sectional area, n: the number of strands, L: Length from the 4th measuring point to the 8th, ϕ_n: Bond periphery of two or more EC strands surface ($\phi_n = \phi \times n$)]
The integration method of incremental strain is shown in Fig. 6. It was assumed that strain distributions were the straight line passes along two points, 4th and 8th strain (colored part in Fig. 6). In addition, calculations (ΔS) and measurements (δ) are the almost same values. (ΔS is about 90 percent of δ.), it is not concerned with load level.
Fig. 7(a) shows the average bond stress (τ) - ΔS relation about 1-, 3-, and 5-EC strands in compressive strength of cement grout ${}_G\sigma_B$ = 90N/mm^2 level. And, Fig. 7(b) shows the average bond stress (τ) - ΔS relation in 5-, 10-EC strands in ${}_G\sigma_B$ = 40N/mm^2 level. Difference in cement grout compressive strength and the number of EC strands had little influence on τ -ΔS relation. The average bond stress (τ) occurred about

0.6N/mm^2 immediately after loading, and increased gradually. Thereafter, τ reached 1.10N/mm^2 around ΔS = 2.5mm(τ_{max} = 1.10N/mm^2). Even after average bond stress (τ) reached τ_{max}, keeping the value mostly was seen. In addition, an average bond stress is used by the latter P- δ relation model.
Next, the bond periphery of prestressing strand surface (ϕ) in the case two or more EC strands arranged is considered. Fig. 7(a) shows that τ_{max} is 1.10N/mm^2 in a single EC strand type. If it is assumed that τ_{max} is fixed (it is equal to that of a single EC strand type), without depending on the number of EC strands, ϕ will be calculated from an equation (2).

$$\phi = \frac{(\Delta\varepsilon_4'\text{-}\Delta\varepsilon_8')\times_p E_{exp} \times a_p \times n}{L \times_{EC}\tau_{max}} \tag{2}$$

Where [$\Delta\varepsilon_4'$, $\Delta\varepsilon_8'$: Incremental strain at the 4th or 8th strain measuring point at the time of maximum bond stress, $_{EC1}\tau_{max}$: Average bond strength of a single EC strand type (=1.10 N/mm^2, Fig. 7(a))]

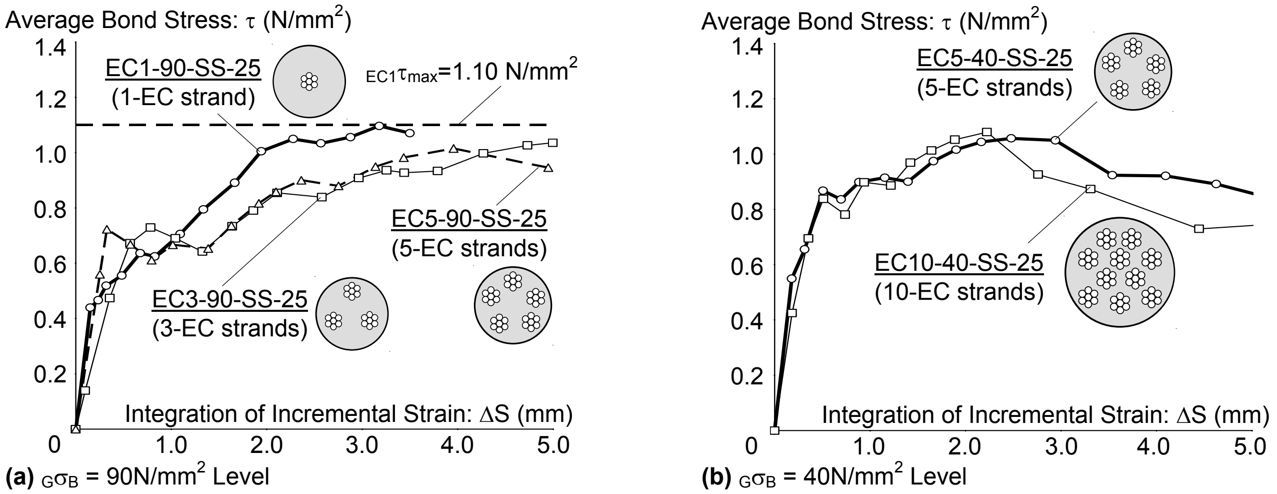


Fig. 7. Average Bond Stress (τ) - Integration of Increase Strain (ΔS) Relationship

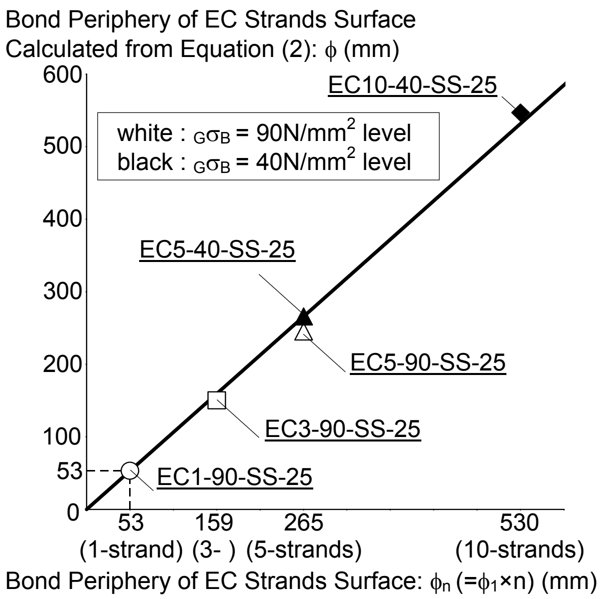


Fig. 8. Bond Periphery of EC Strands Surface (ϕ)

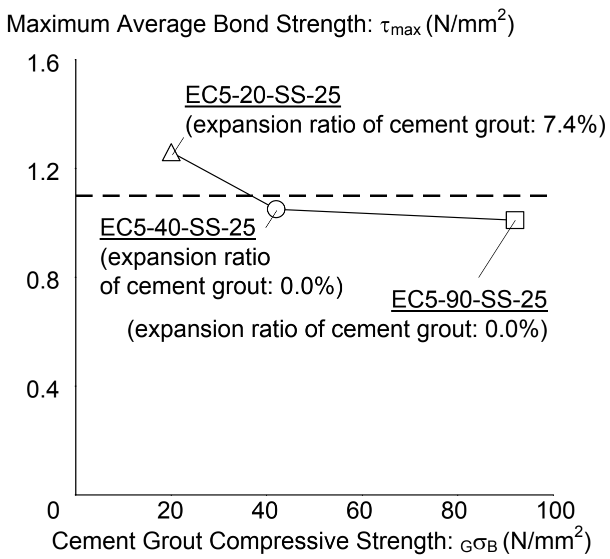


Fig. 9. Cement Grout Compressive Strength ($_G\sigma_B$) - Maximum Average Bond Strength (τ_{max}) Relationship

ϕ calculated from the equation (2) and ϕ_n are shown in Fig. 8. Here, ϕ_n is calculated from multiplying bond periphery of 1-EC strand surface (ϕ_1) by the number of strands (n). The figure shows that it is the result of both corresponding. Therefore, bond periphery of two or more EC strands surface (ϕ) is evaluated multiplying a bond surface of 1-EC strand (ϕ_1) by the number of strands (n).
Next, the relation between compressive strength of cement grout (${}_G\sigma_B$) and average bond strength (τ_{max}) is considered. Fig. 9 shows τ_{max} depending on the cement grout compressive strength (about 20, 40, and 90 N/mm^2) in the case of 5-EC strands. Here, the bond periphery of 5-EC strands surface uses ϕ_5 (=ϕ_1 × 5). τ_{max} was, without depending on cement grout compressive strength, about 1.10N/mm^2. In ${}_G\sigma_B$ = 20 N/mm^2 specimen, τ_{max} was high a little (τ_{max} = 1.26 N/mm^2), this was considered to be influence due to expansion ratio of cement grout (7.4%).

PREDICT METHOD LOAD (P) – SLIP DISPLACEMENT (δ) RELATIONAL CALCULATION

Model

In this chapter, the method to predict the tention force (P) - bond slip displacement (δ) relation is proposed by modeling the bond behavior between two or more EC strands and cement grout. In this paper, the slip displacement (δ) against tention force (P) assumes that it is equal to the incremental strain integration (ΔS). In order to calculate ΔS, the strain distribution of EC strand and the average bond stress of EC strands with cement grout are modeled from the test result.
In addition, the coverage of this model is the test range of this paper; the diameter of EC strands is 12.7mm, the number of strands is 1-10 strands, cement grout compressive strength is 20~90N/mm^2.
Strain distributions of EC strand were modeled as followings (shown in Fig. 10.).
(1) At the time of loading: the strain distributions is linear, *(a) loading*, *(b) after load (peak load)*.
(2) At the time of unloading: the bond stress occurred to the opposite direction in the case of loading, *(c) unloading*, *(d) after unload*.
(3) Re-loading: the EC strand is loaded from the state of “after unload”, *(e) re-loading.*

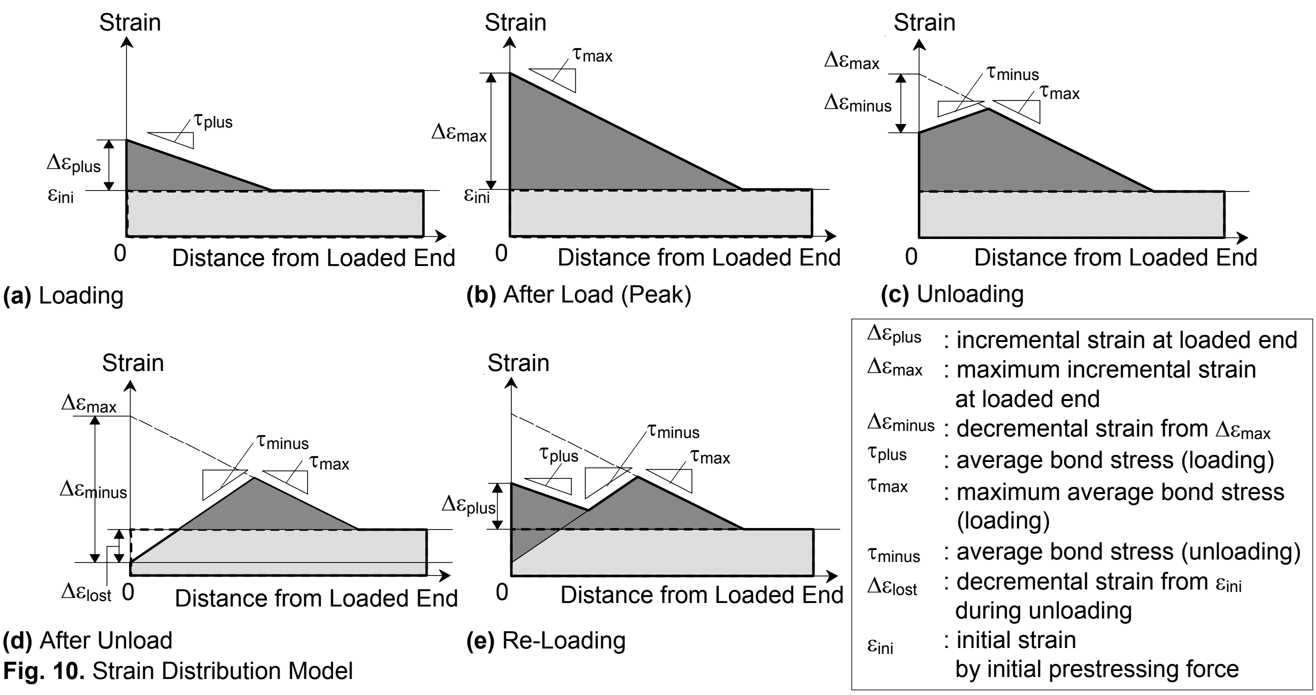
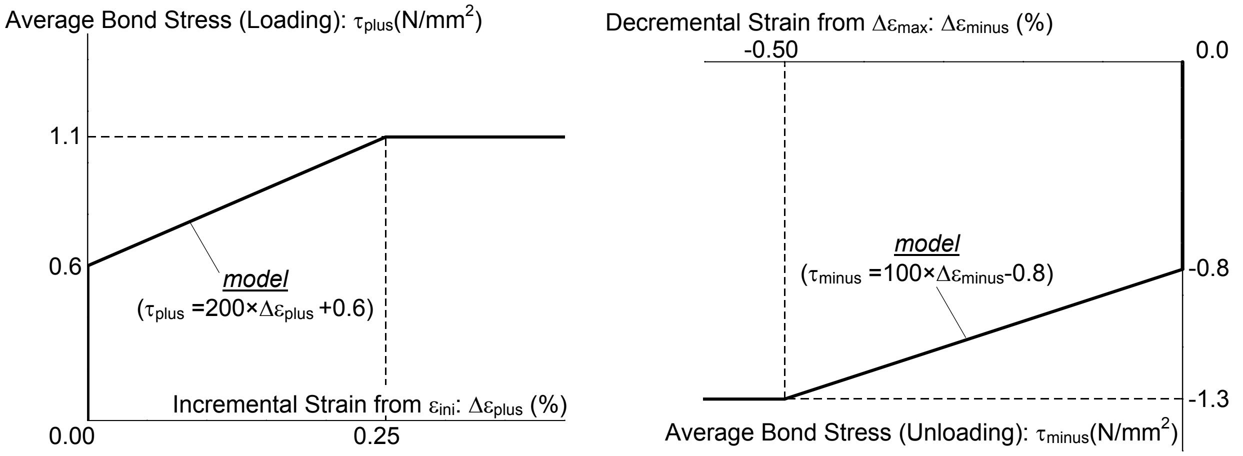


Fig. 10. Strain Distribution Model

Fig. 11 shows τ-$\Delta\varepsilon$ relation models. Fig. 12 shows the past maximum incremental strain at the loading end ($\Delta\varepsilon_{max}$) - decremental strain after unload ($\Delta\varepsilon_{lost}$) relation model. The values in Fig. 11, 12 are determined from the experimental result using that shown in Fig. 7. The details of calculation method in each state are explained below:

(1) In the case of loading: average bond stress (τ_{plus}) during loading is calculated from incremental strain ($\Delta\varepsilon_{plus}$) against Load (P) (using Fig. 11(a)). Strain distribution is assumed to be linear distribution, and length of distribution (bond length) is calculated using τ_{plus} and ϕ (= n x ϕ_1) (Fig. 10(a), (b)).
(2) In the case of unloading: average bond stress (τ_{minus}) during unloading is calculated from decremental strain at the loaded end ($\Delta\varepsilon_{minus}$) using Fig. 11(b). Strain distribution is determined as well as the case of (1) (Fig. 10(c)). Moreover, after unload, $\Delta\varepsilon_{lost}$ calculated using Fig.12, and similarly the strain distribution is determined (Fig. 10(d)).
(3) In the case of re-loading: The state of (e) is adding the state of (a) to the state (d). The strain distribution is calculated with Fig. 10(e).
In addition, The strain distributions of calculation from Fig. 10, 11, and 12 are shown in Fig.13. Fig.13 also shows the experimental result. The strain distribution of calculation is in agreement with that of test result.



(a) Loading **(b)** Unloading

Fig. 11. Average Bond Stress (τ) – Incremental (Decremental) Strain at Loaded End ($\Delta\varepsilon$) Model

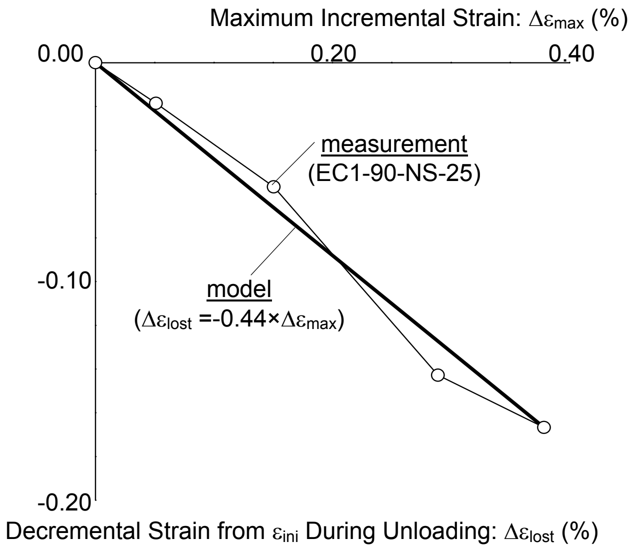


Fig. 12. $\Delta\varepsilon_{max}$ – $\Delta\varepsilon_{lost}$ Model (at Loading End)

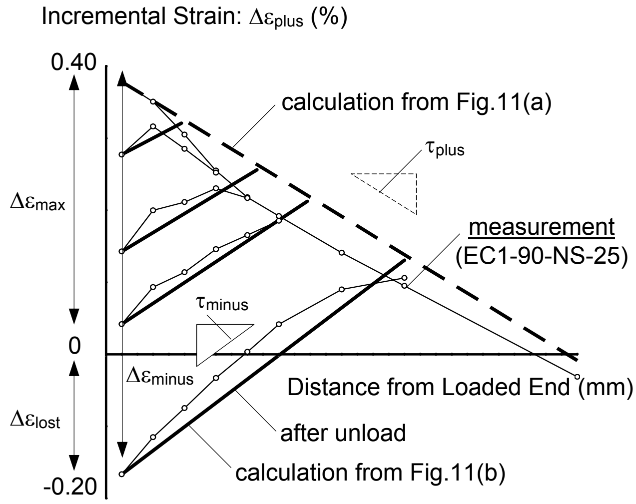
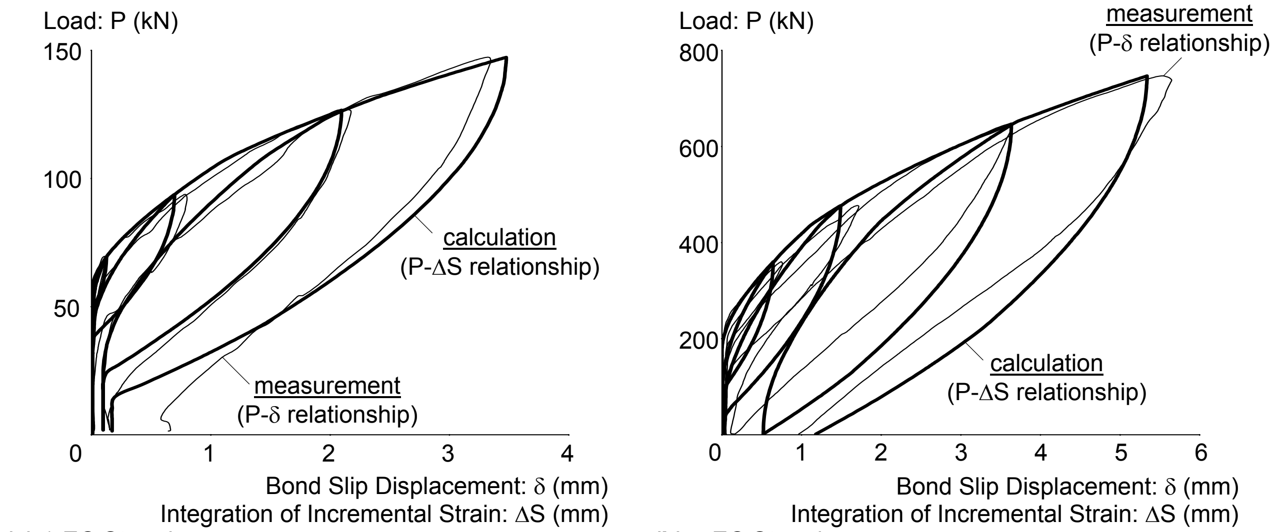


Fig. 13. Proposed Strain Distribution Model and Measurement

Verification of a Proposal Model

Fig. 14 shows the P-ΔS (P- δ) relation of calculation and P- δ relation of test results. 1-EC strand type (EC1-90-SS-25) and 5-EC strands type (EC5-90-SS-25) is shown in Fig.14(a) and (b), respectively. As shown in Fig. 14(a) and (b), Good agreement between the calculation and the test can be seen in the stiffness, the decrease of stiffness and residual displacement. So, the proposed method is useful to predict for the tension force (P) - slip displacement (δ) relation of EC strand.



(a) 1-EC Strand **(b)** 5-EC Strands

Fig. 14. Calculation (P-ΔS) and Measurement (P-δ)

CONCLUSION

The bond experiment of EC strands with cement grout is conducted, under the conditions of the diameter of EC strands is 12.7mm, the number of strands is 1~10 strands, cement grout compressive strength is 20~90N/mm^2. The knowledge shown below was acquired.

1) The bond stress of epoxy resin coated prestressing strand (EC strand) is smaller than that of a prestressing deformed bar, and it is constantly occurred throughout required bond length. In the case of unloading, the bond stress occurred to the opposite direction in the case of loading. Further, the two value of maximum average bond stress was almost equal.
2) The epoxy resin coating have little influence on the tension force (P) – bond slip displacement (δ) relation, as long as incremental load over initial prestressing force reaches 0.5P_y/strand.
3) Initial prestressing force does not afect influence on P-δ relation, after EC strands began to slip until it reached the yield load level.
4) The steel sheath have little effect on P-δ relation under the conditions cement grout compressive strength is 90N/mm^2.
5) It can be evaluate bond periphery of two or more EC strands surface (ϕ) by multiplying bond periphery of 1-EC strand surface (ϕ_1) by the number of strands (n). That is, $\phi = \phi_1 \times n$.
6)A prediction method for the tension force (P) - displacement (δ) relation is proposed by modeling the strain distribution, maximum average bond stress and bond periphery of two or more EC strands surface (ϕ).

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