EXPERIMENTAL STUDY ON SHEAR STRENGTH OF THE PHC PILE WITH LARGE DIAMETER

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SUMMARY

In order to investigate the ultimate shear behavior of the PHC piles and prevent the piles from the brittle failure, we carried out the anti-symmetric bending shear experiments by proposing the idea of filling the concrete into the hollow part of the pile and increasing the amount of spiral reinforcement. As the result, it shows that in case of increasing the amount of spiral reinforcement, the average shear stress increased at the ultimate strength in shear. And, in case of filling the concrete into the hollow part of the pile, the ultimate strength increased but the brittle fracture happened. In case of using both methods, it makes clear that the deformation behavior becomes better and the same time the ultimate strength increased.

INTRODUCTION

Current pile foundation design of the pretentioned spun high strength concrete pile (hereafter referred as PHC pile) prescribed by JIS, only assign the elastic design basing on the allowable stress design method, the ultimate failure behavior has not been examined. After the Great Earthquake in Hanshin and Awaji areas in 1995, the interested in the pile structure design for seismic buildings has been risen up sharply. Moreover, the increasing size of building structures has resulted in the increased usage of large diameter piles. In large diameter piles, the length from the pile head to the inflection point (the so-called shear span) becomes shorter relative to the large pile diameter. A smaller shear span means that the shear failure tends to occur. So we have carried out shear failure experiments to understand the shear failure behavior of large diameter PHC piles. For the PHC piles, it was pointed that the small deformations and the brittle failures occur when the horizontal force works based on the current design, especially the large diameter PHC piles shows such behavior [Kishida,1998]. It shows that to fill the concrete into the hollow part of the pile can improve the deformation capacity of the PHC piles. It can also shear the compression force caused by axial force and bending moment, reduce the movement of the neutral axis, and prevent the piles from the brittle bending compression failure [Kokusho,1987].

This report is a series study of grasping the seismic capacity of the PHC pile. In the previous report [Kishida,1998], we performed the anti-symmetric bending shear experiment, evaluated the influence of each parameter on the shear ultimate strength of the large diameter PHC pile based on the present JIS standard, and proof the conformability of the various calculation formula of the shear strength. In this research, we carried out the anti-symmetric bending shear experiments by proposing the idea of filling the concrete into the hollow part of the pile and increasing the amount of spiral reinforcement.

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EXPERIMENTAL PROCEDURE

Specimens

It shows the list of test specimens on Table 1, and also shows the shapes and the sizes of them on Fig.1. Series are JP3 300φ and JP12 1200φ test specimens reported in the previous study [Kishida,1998], the amount of spiral reinforcement are increasing by 5 ,10 and 15 times. Axial force is long time loading and ultimate loading. Series have the same amount spiral reinforcement as the specimens reported in the previous reported, plus the series I specimens with the concrete filled into the hollow part of the pile.

Table 1: List of Test Specimen

Specimens – Concrete filled in the hollow part of pile: No Filling (Series‡ T)	Filling (Series‡ U)	Diameter and Thickness (mm)	Effective Prestress (N/mm²)	Axial Reinforcement Number-Diameter (%)	Spiral Reinforcement: Diameter Pitch	pw¥wƒ Þ (N/mm²)	Axial Force (kN)
JP3-100-15-35	JPF3-100-15-35-1	JP3 300ƒ Ó t=60 t/D=0.2 As=45200 mm²	Type C 9.81	10-9.0ƒ Ó 1.41	3.2ƒ Ó 50	1.45	343
JPE3-100-15-35-5	JPF3-100-15-35-5				3.2ƒ Ó+6.0ƒ Ój 45	7.25	
JPE3-100-15-35-10	JPF3-100-15-35-10				3.2ƒ Ó+U6.4ƒ Ój 45	15.78	
JPE3-100-15-35-15	JPF3-100-15-35-15				5.5ƒ Ó+U7.4ƒ Ój 45	23.64	
JP3-100-15-105	JPF3-100-15-100-1				3.2ƒ Ó 50	1.45	981
JPE3-100-15-100-5	JPF3-100-15-100-5				3.2ƒ Ó+6.0ƒ Ój 45	7.25	
JPE3-100-15-100-10	JPF3-100-15-100-10				3.2ƒ Ó+U6.4ƒ Ój 45	15.78	
JPE3-100-15-100-15	JPF3-100-15-100-15				5.5ƒ Ó+U7.4ƒ Ój 45	23.64	
JP12-80-15-35	JPF12-80-15-35-1	JP12 300ƒ Ó t=37.5 t/D=0.125 As=30900 mm²	Type B 7.85	6-9.0ƒ Ó 1.24	2.9ƒ Ó 45	2.11	343
JPE12-80-15-35-5	JPF12-80-15-35-5				6.5ƒ Ó45	10.60	
JPE12-80-15-35-10	JPF12-80-15-35-10				U6.4ƒ Ó45	22.67	
JPE12-80-15-35-15	JPF12-80-15-35-15				4.0ƒ Ó+U7.4ƒ Ój 45	34.24	
JP12-80-15-105	JPF12-80-15-100-1				2.9ƒ Ó 45	2.11	981
JPE12-80-15-100-5	JPF12-80-15-100-5				6.5ƒ Ó45	10.60	
JPE12-80-15-100-10	JPF12-80-15-100-10				U6.4ƒ Ó45	22.67	
JPE12-80-15-100-15	JPF12-80-15-100-15				4.0ƒ Ó+U7.4ƒ Ój 45	34.24	
JP12-100-15-35	JPF12-100-15-35-1		Type C 9.81	8-9.0ƒ Ó 1.66	2.9ƒ Ó 45	2.11	343
JPE12-100-15-35-5	JPF12-100-15-35-5				6.5ƒ Ó45	10.60	
JPE12-100-15-35-10	JPF12-100-15-35-10				U6.4ƒ Ó45	22.67	
JPE12-100-15-35-15	JPF12-100-15-35-15				4.0ƒ Ó+U7.4ƒ Ój 45	34.24	
JP12-100-15-105	JPF12-100-15-100-1				2.9ƒ Ó 45	2.11	981
JPE12-100-15-100-5	JPF12-100-15-100-5				6.5ƒ Ó45	10.60	
JPE12-100-15-100-10	JPF12-100-15-100-10				U6.4ƒ Ó45	22.67	
JPE12-100-15-100-15	JPF12-100-15-100-15				4.0ƒ Ó+U7.4ƒ Ój 45	34.24	

Table 2-1: Mechanical Properties of Concrete

	$_C\sigma_B$ (N/mm²)	$_C\sigma_t$ (N/mm²)	$E_{1/3}$ (N/mm²)
Pile	91.16 96.03	6.76 7.12	3.46 3.65*10^4
Average	**93.45**	**6.93**	**3.55*10^4**
Filling	37.83 41.01		2.71 2.92*10^4
Average	**39.60**		**2.82*10^4**

$_C\sigma_B$ ¥¥¥Compressive Strength, $_C\sigma_t$ ¥¥¥Cleavage Strength,

$E_{1/3}$ ¥¥¥Elastic Modulus

Table 2-2: Mechanical Properties of Steel

	σ_y (N/mm²)	σ_t (N/mm²)	E_s (N/mm²)
2.9ƒ Ó		609.4	
3.2ƒ Ó		551.8	
4.0ƒ Ó		528.5	
5.5ƒ Ó		666.4	
6.0ƒ Ó		549.4	
6.5ƒ Ó		598.4	
6.4ƒ Ó(PC Steel rod)	1412.6	1481.3	2.00*10^5
7.4ƒ Ó(PC Steel rod)	1392.6	1431.5	1.93*10^5
9.0ƒ Ó(PC Steel rod)	1357.8	1412.2	1.89*10^5

σ_y ¥¥¥Yield Strength, σ_t ¥¥¥Cleavage Strength,

E_s ¥¥¥Elastic Modulus

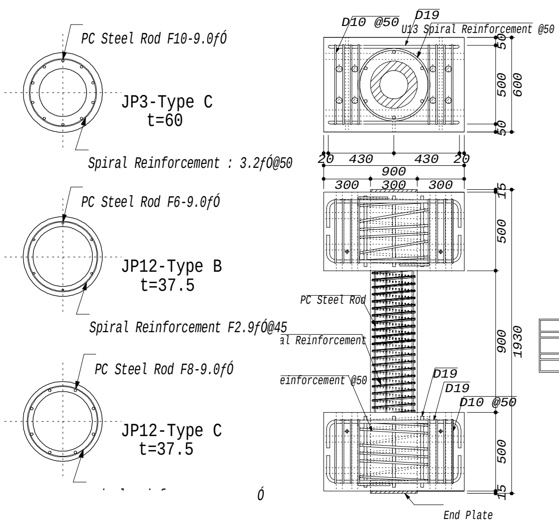


Figure1: Details of Specimen

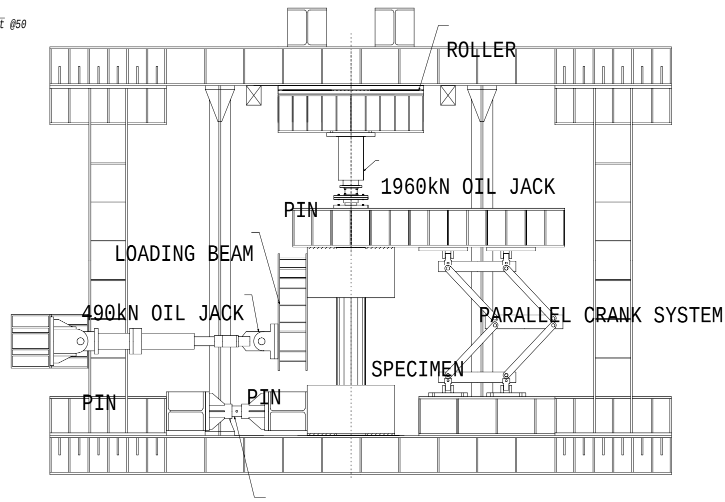


Figure2: Loading Setup

The spiral reinforcement used on JP3 is 3.2φ@50mm, and 2.9φ@45mm for JP12 had. The amount of spiral reinforcement (pwwσy) is calculated by the tensile stress (wσy) multiply the spiral reinforcement ration (pw) in this case. Concrete was filled into the hollow part of piles along over the pile full length. Shear span ration was 1.5 that is the same as previous report. The description of the mark of the specimens, refer to Appendix 1. The test specimens are 42 as total.

Table 2-1 and table 2-2 shows the mechanical properties of the material.

Loading Method

Figure 2 shows the loading setup. This loading was performed under an anti-symmetric deformation method. After loading the fixed axial force by using 1962 kN oil jack, the axial force maintains and add the one direction monotonous load to the loading beam which was fitted in the upper stub.

Table 3-1: List of Experimental Effect and Each Stress Computation Value□In case of Series□□

Specimens	Experimatal Value					Calculation Value			Exp./Cal.			Failure Mode
	ƒ Ð+ƒ Ð (N/mm²)	Q1exp (kN)	Q2exp (kN)	Q3exp (kN)	Q3exp/A1 (N/mm²)	Q1cal (kN)	Q2cal (kN)	Q3cal (kN)	Q3exp /Q1cal	Q2exp /Q2cal	Q3exp /Q3cal	
JP3-100-15-35	16.39	144.9	233.1	242.8	*4.95*	298.0	135.3	197.1	0.81	1.72	1.23	S
JPE3-100-15-35-5	14.61	129.3	—	344.2	*6.45*	298.0	135.3	242.6	1.16	—	1.42	B
JPE3-100-15-35-10	15.86	138.0	—	374.6	*7.16*	298.0	135.3	293.7	1.26	—	1.28	B
JPE3-100-15-35-15	17.04	109.6	—	370.4	*7.96*	298.0	135.3	304.8	1.24	—	1.22	B
JP3-100-15-100	27.16	224.0	299.3	302.4	*5.92*	387.5	176.7	261.2	0.78	1.69	1.16	S-C
JPE3-100-15-100-5	29.86	231.3	298.2	321.1	*6.63*	384.2	176.7	317.3	0.84	1.69	1.01	C
JPE3-100-15-100-10	29.73	253.4	457.9	472.4	*9.92*	384.2	176.7	372.9	1.23	2.59	1.27	C
JPE3-100-15-100-15	26.09	251.1	562.0	562.9	*10.37*	384.2	176.7	416.9	1.47	3.18	1.35	B
JP12-80-15-35	16.85	142.9	171.6	188.7	*5.30*	229.6	93.4	140.0	0.82	1.84	1.35	S
JPE12-80-15-35-5	17.20	100.8	202.8	254.5	*7.21*	228.0	93.4	173.4	1.12	2.17	1.47	C
JPE12-80-15-35-10	19.09	103.5	257.4	266.7	*8.06*	228.0	93.4	210.5	1.17	2.76	1.27	C
JPE12-80-15-35-15	19.06	123.8	192.1	233.9	*7.44*	228.0	93.4	223.5	1.03	2.06	1.05	C
JP12-80-15-100	32.60	—	213.9	226.7	*6.21*	301.4	131.6	201.9	0.75	1.63	1.12	S-C
JPE12-80-15-100-5	37.61	91.8	188.3	223.9	*6.93*	303.9	131.6	247.5	0.74	1.43	0.90	C
JPE12-80-15-100-10	35.63	98.1	187.3	278.5	*8.14*	303.9	131.6	301.8	0.92	1.42	0.92	C
JPE12-80-15-100-15	36.89	211.1	276.5	328.7	*9.99*	303.9	131.6	330.3	1.08	2.10	1.00	C
JP12-100-15-35	17.30	172.4	187.0	208.5	*5.44*	262.1	97.4	158.7	0.80	1.92	1.31	S
JPE12-100-15-35-5	20.12	204.5	243.6	287.3	*8.87*	261.9	97.4	182.6	1.10	2.50	1.57	C
JPE12-100-15-35-10	18.51	108.7	198.8	276.4	*7.82*	261.9	97.4	224.8	1.06	2.04	1.23	C
JPE12-100-15-35-15	19.55	118.6	244.1	325.3	*9.51*	261.9	97.4	246.7	1.24	2.51	1.32	C
JP12-100-15-100	31.45	—	214.3	223.2	*5.59*	315.9	133.9	222.7	0.71	1.60	1.00	C
JPE12-100-15-100-5	38.09	160.6	348.8	364.7	*10.88*	320.6	133.9	266.8	1.14	2.61	1.37	C
JPE12-100-15-100-10	34.06	237.6	403.8	403.8	*10.81*	320.6	133.9	322.9	1.26	3.02	1.25	C
JPE12-100-15-100-15	38.14	234.0	364.0	368.4	*10.96*	320.6	133.9	352.7	1.15	2.72	1.04	C

Attention The experiment result of the hatching is to excerpt from Reference[Kishida,1998]

Table 3-2: List of Experimental Effect and Each Stress Computation Value□In case of Series□□

Specimens	Experimatal Value					Calculation Value				Exp./Cal.				Failure Mode
	ƒ Ð+ƒ Ð (N/mm²)	Q1exp (kN)	Q2exp (kN)	Q3exp (kN)	Q3exp/A2 (N/mm²)	Q1cal (kN)	Q3cal (kN)	Q4cal (kN)	Q5cal (kN)	Q3exp /Q1cal	Q3exp /Q3cal	Q3exp /Q4cal	Q3exp /Q5cal	
JPF3-100-15-35-1	13.79	134.2	267.6	267.6	*3.79*	298.2	188.9	232.6	248.6	0.90	1.42	1.15	1.08	S
JPF3-100-15-35-5	14.71	114.5	239.3	303.3	*4.29*	298.2	238.0	274.2	321.2	1.02	1.27	1.11	0.94	B/S
JPF3-100-15-35-10	14.34	177.9	—	361.2	*5.11*	298.2	280.1	316.5	375.8	1.21	1.29	1.14	0.96	B
JPF3-100-15-35-15	14.42	172.5	—	377.9	*5.35*	298.2	309.4	340.6	418.4	1.27	1.22	1.11	0.90	B
JPF3-100-15-100-1	22.73	218.5	381.6	401.2	*5.68*	392.0	256.4	302.0	292.7	1.02	1.56	1.33	1.37	S
JPF3-100-15-100-5	24.11	188.4	401.5	478.4	*6.77*	392.0	323.0	357.4	373.0	1.22	1.48	1.34	1.28	B/S
JPF3-100-15-100-10	23.97	233.5	434.2	474.7	*6.72*	392.0	380.2	408.1	435.8	1.21	1.25	1.16	1.09	B/S
JPF3-100-15-100-15	23.16	197.9	—	550.4	*7.79*	392.0	420.0	440.6	455.4	1.40	1.31	1.25	1.21	B
JPF12-80-15-35-1	11.64	174.3	217.1	250.2	*3.54*	230.4	132.1	205.8	239.9	1.09	1.89	1.22	1.04	S
JPF12-80-15-35-5	13.11	147.9	—	271.0	*3.84*	230.4	171.9	239.7	332.7	1.18	1.58	1.13	0.81	B
JPF12-80-15-35-10	12.79	184.1	—	267.9	*3.79*	230.4	205.2	266.2	410.4	1.16	1.31	1.01	0.65	B
JPF12-80-15-35-15	12.61	167.8	—	280.7	*3.97*	230.4	229.2	283.3	449.7	1.22	1.22	0.99	0.62	B
JPF12-80-15-100-1	20.01	129.0	179.8	297.8	*4.22*	331.0	198.6	269.8	286.7	0.90	1.50	1.10	1.04	S
JPF12-80-15-100-5	20.32	120.5	—	295.1	*4.18*	331.0	258.4	309.7	361.6	0.89	1.14	0.95	0.82	B
JPF12-80-15-100-10	20.82	139.9	—	260.9	*3.69*	331.0	308.3	345.9	454.1	0.79	0.85	0.75	0.57	B
JPF12-80-15-100-15	20.88	192.1	—	366.3	*5.18*	331.0	344.5	377.0	493.8	1.11	1.06	0.97	0.74	B
JPF12-100-15-35-1	14.85	132.5	182.3	204.4	*2.89*	266.0	145.7	225.5	272.1	0.77	1.40	0.91	0.75	B/S
JPF12-100-15-35-5	14.39	148.9	—	286.9	*4.06*	266.0	187.4	249.0	343.8	1.08	1.53	1.15	0.83	B
JPF12-100-15-35-10	13.44	177.5	—	335.2	*4.74*	266.0	222.2	284.3	395.2	1.26	1.51	1.18	0.85	B
JPF12-100-15-35-15	14.74	168.2	—	332.5	*4.71*	266.0	247.5	304.0	463.6	1.25	1.34	1.09	0.72	B
JPF12-100-15-100-1	23.72	—	231.4	289.2	*4.09*	356.5	215.6	292.7	323.7	0.81	1.34	0.99	0.89	B/S
JPF12-100-15-100-5	21.84	337.8	—	426.5	*6.04*	356.5	277.4	326.7	370.6	1.20	1.54	1.31	1.15	B
JPF12-100-15-100-10	21.70	257.1	—	472.4	*6.69*	356.5	328.9	368.6	435.9	1.33	1.44	1.28	1.08	B
JPF12-100-15-100-15	23.68	255.1	—	475.3	*6.73*	356.5	366.2	393.9	520.6	1.33	1.30	1.21	0.91	B

Attention ƒ Ð+ƒ Ð:Composite Axial Stress A1 Ring Section A2 Circle Section

Q1exp :Flexural Crack Strength **Q2exp** :Shear Crack Strength **Q3exp** :Ultimate Shear Strength

Q1cal :Shear Strength with calculated in e-function **Q2cal** :Calculation Value in Building Center of Japan [Bilding Center of Japan,1993]

Q3cal :Calculated Ultimate Shear Strength[Gotoh,1985] **Q4cal** :Calculated Ultimate Shear Strength[Gotoh,1986]

Q5cal :Calculated Ultimate Shear Strength[AIJ,1990]

S Shear Failure B Bending Failure *S-C* Shear-Compression Failure *B/S* Bending and Shear Failure C Comression Failure

EXPERIMENTAL RESULTS

In Case of Increasing only the Amount of Spiral Reinforcement

Load – Displacement Relationship

Table 3 shows the experimental results and failure modes. Figure 3 shows the load – displacement relationship of the specimens with the classified on Type C amount of the effective prestress. By increasing the mount of spiral reinforcement, the maximum strength rises by about 1.5 - 1.7 times. In the case of the low axial force (Fig.3-(a)), by putting a amount of spiral reinforce ment more than 5 times, the displacement at the maximum strength becomes larger than the test specimen of the present amount of spiral reinforcement. Also, it shows the transformation efficiency that the strength decline after the maximum strength was very stable gently. In the case of high axial force (Fig.3-(b)), the displacement to the maximum strength becomes smaller oppositely and the transformation efficiency didn't become good till putting the 15 times amount of spiral reinforcement.

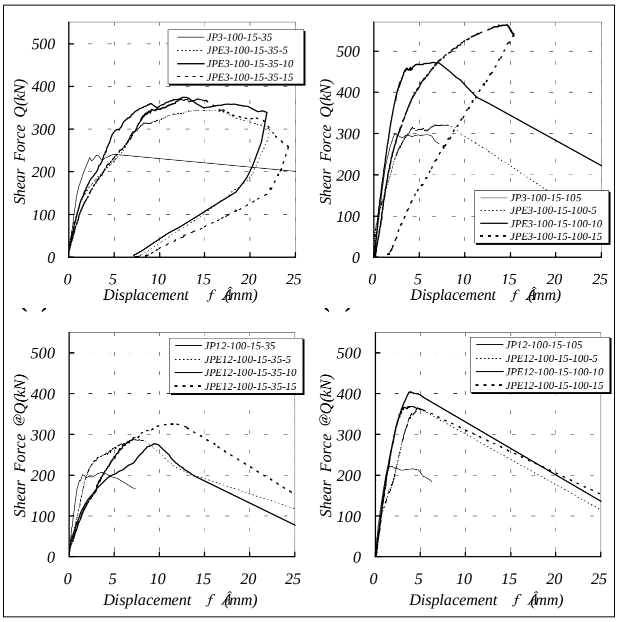
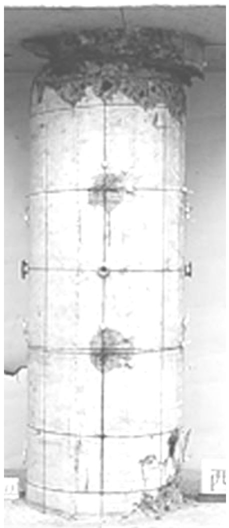
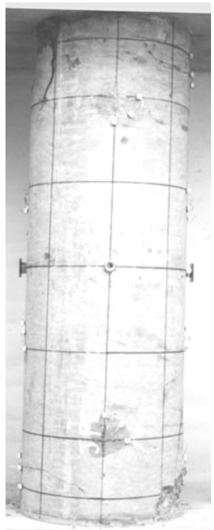


Figure3: Relationship between Load and Displacement



(a)Compression Failure

JPE12-100-15-100-15



(b)Bending Failure
JPE3-100-15-35-15

Photo 1: Final Failure Figure

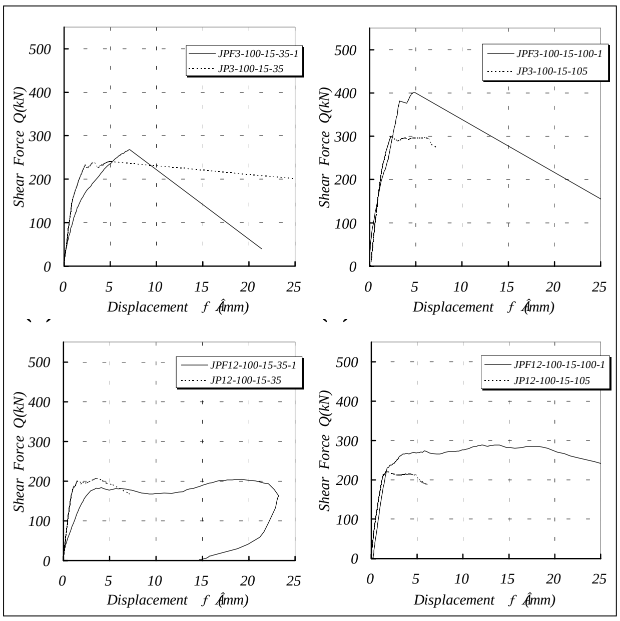
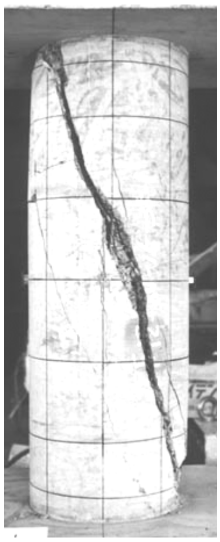
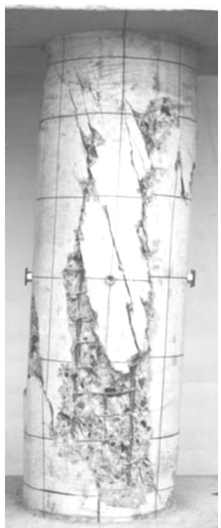


Figure4: Relationship between Load and Displacement



(a)Shear Failure

JPF12-80-15-35-1



(b)Bending and Shear Failure
JPF12-100-15-35-1

Photo 2: Final Failure Figure

In the case of series JP12 that the thickness is thin, the displacement to the maximum strength becomes smaller, in case of the high axial force (Fig.3-(d)), the test specimens which has the amount of spiral reinforcement more than 5 times, the compression failure occur when it reaches to the maximum strength. Then, the transformation efficiency didn't become good even if it had the amount of spiral reinforcement by 15 times.

Failure Character

Photo 1 shows the example of the final failure character. In the case of low axial force of JP3 series, since the amount of spiral reinforcement increased by 5 times, the failure mode changed into bending failure from shear failure. In the case of the high axial force, since the amount of spiral reinforcement increased by 15 times, the failure mode changed into bending failure from compression failure.

In case of the Filled Concrete in the Hollow Part of Piles

Load – Displacement Relationship

Figure 4 shows load–displacement relationship of the specimens which has concrete fills into the hollow part of pile according to the current JIS code. In the case of low axial force of series JP3 (Fig.4-(a)), though the displacement at the maximum strength became larger than the present JIS pile, the shear failure occur when it reaches the maximum strength. In the case of the high axial force (Fig.4-(b)), the maximum strength rose about 1.3 times but the displacement at the maximum strength became smaller. In the case of the low axial force of series JP12 (Fig.3-(c)), the maximum strength changes hardly in the case of the present JIS pile. In the case of the high axial force (Fig.3-(d)), the maximum strength rose about 1.2 times. The displacement became larger than the present JIS pile case, the declining of the strength became gentle.

Failure Character

Photo 2 shows the example of the final failure character. The failure mode does not become ductility failure mode even if the hollow part of the pile is filled with concrete, the failure mode became shear failure or bending and shear failure mode.

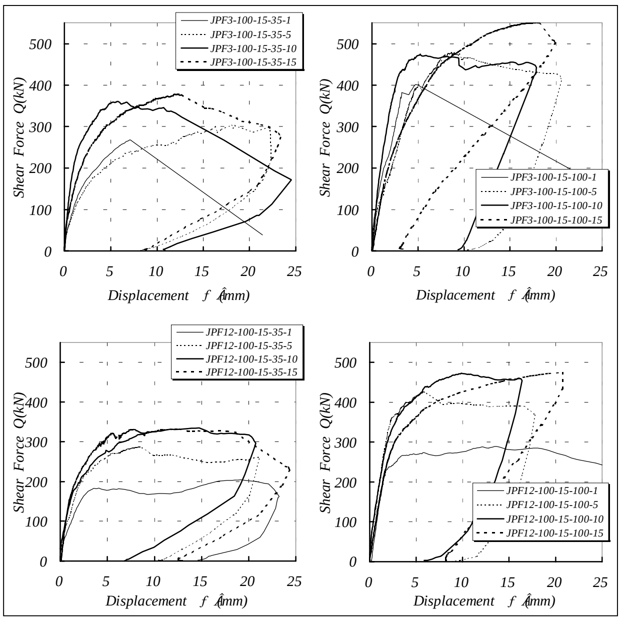
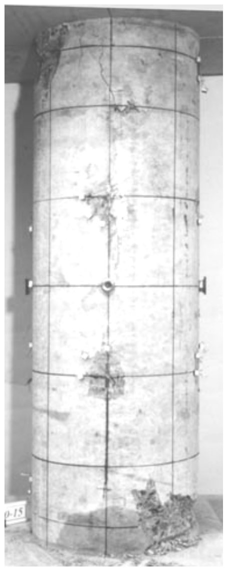


Figure5: Relationship between Load and Displacement



Bending Failure
JPF12-100-15-100-15

Photo 3: Final Failure Figure

In case of Filling the Concrete into the Hollow Part of the Pile and Increasing the Amount of Spiral Reinforcement.

Load – Displacement Relationship

Figure 5 shows the load–displacement relationship of the specimens with the classified on Type C effective prestress. As the amount of spiral reinforcement increasing, in the case of the low axial force specimen(Fig.5-(a),(c)), the maximum strength rose about 1.2 ~ 1.4 times compared to the specimen with the 1 time amount of spiral reinforcement. In the case of the high axial force (Fig.5-(b),(d)), the maximum strength becomes about 1.9 times bigger.
In the case of low axial force of series JP3 (Fig.5-(a)), for the specimen with the 1 time and 5 times amount of spiral reinforcement, the displacement at the maximum strength becomes larger. And as the amount of the spiral reinforcement becomes 10 times, 15 times bigger, the displacement at the maximum strength becomes smaller. The specimen which has 15 times amount of spiral reinforcement, the declining of the strength after the maximum strength became gentle. In the case of the high axial force (Fig.5-(b)), the amount of spiral reinforcement increases over 5 times, both the maximum strength and the displacement capacity become better. In the case of series JP12 specimens (Fig.5-(c),(d)), the amount of spiral reinforcement increases over 5 times, the declining of the strength after the maximum strength becomes gentle and the displacement becomes larger.

Failure Character

In the case of series JP3 specimen, the failure mode of 3 test specimens which the amount of spiral reinforcement is 5 times and 10 times more, the bending and shear failure occur. For the other specimens, the bending failure. In the case of the thin thickness specimens, by filling the concrete into the hollow part of the pile and increasing the amount of spiral reinforcement more than 5 times, it can change into the ductile bending failure from the brittle shear failure.

COMPARISON BETWEEN THE MAXIMUM STRENGTH AND THE CALCULATION VALUE

It was reported that the ultimate shear strength formula of the pile is using the method of substituting the pile section into the diagonal section and the ultimate shear strength formula of the column at present [Gotoh,1985]. Incidentally, the effective of the reinforcement is decreasing compare to the rectangle case because the spiral reinforcement shape was circular, here, it reduced the value of pw□wσy by 0.785 times in both calculation formulas [Watanabe,1987].
Figure 6 shows the comparison between the experiment value (Q3exp) and the calculation value (Q3cal) of the specimen after increasing the amount of spiral reinforcement. Q3exp/Q3cal fitted between 0.8 ~1.2. The

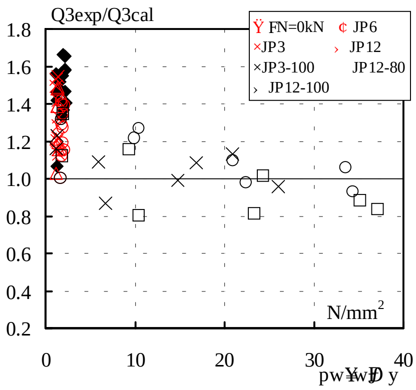


Figure6: Comparison between Experiment Value (Q3exp) and The Shear Ultimate strength formula Computation Value□Q3cal□

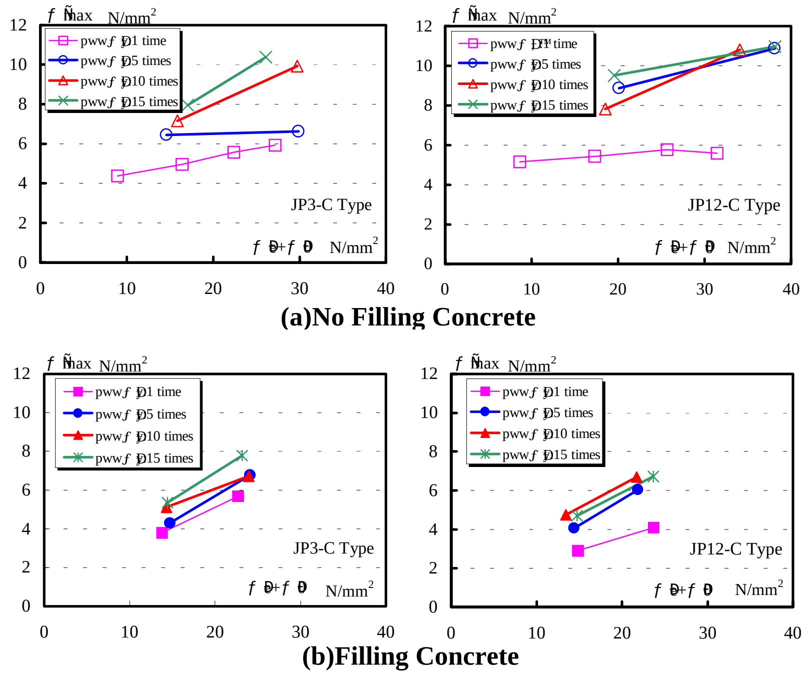


Figure7: Relationship between Ultimate Strength in shear and

experiment value shows good suitableness with the computation value. However, the ratio becomes rather down at the right side when the amount of spiral reinforcement (pw□wσy) becomes larger.

THE INFLUENCE OF EACH PARAMETER ON THE ULTIMATE SHEAR STRENGTH

The average shear stress at the maximum strength is the ultimate shear strength divided by the section area.

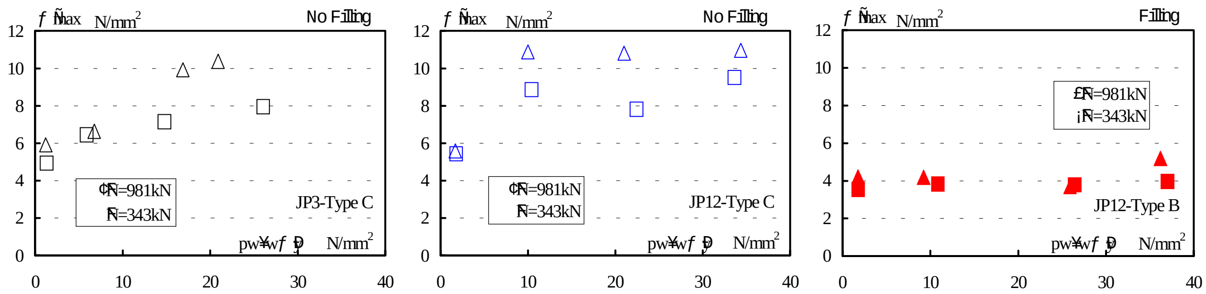


Figure8: Relationship between Ultimate Strength in shear and Amount of Spiral Reinforcement

Influence of the Composite Axial Stress

Figure 7 shows the results after comparing the same thickness (t/D) ratio specimens. As the composite axial stress (σe+σ0) becomes larger, average shear stress at the maximum strength (τmax) becomes larger, too. Here, the composite axial stress (σe+σ0) is the sum of the axial stress (σ0) and the effective prestress (σe).
In the case of the pile without filling concrete inside (Fig.7-(a)), the influence of the composite axial stress depends on the difference of the amount of spiral reinforcement. In the case of the JP3-Type C specimen, even if the composite axial force increases, the shear stress of the specimen with 5 times amount of spiral reinforcement doesn't increase. But when the amount of spiral reinforcement increases by 10 times, 15 times, τmax increases. In the case of JP12-Type C specimen, τmax increases when the amount of spiral reinforcement increases. In the case of filling the concrete into the hollow part of the pile (Fig.7-(b)), the influence of the composite axial force on the shear stress is the same regardless of the difference of the amount of spiral reinforcement. Also, the inclination of the composite axial force is almost the same between the JP3-Type C and the JP12-Type C, though the thickness of the two specimens is different. The effective of the difference t/D isn't shown.

Influence of the Amount of Spiral Reinforcement

Figure 8 shows the comparison of the different axial force but same thickness ratio (t/D) specimens. In the case of the low axial force of JP3 with think thickness, τmax increases when the amount of spiral reinforcement increases but in the case of the high axial force, τmax reaches to the peak with 10 times of amount of spiral reinforcement. In the case of JP3 with thin thickness, no relationship with the axial force, τmax increases when the amount of spiral reinforcement increases,τmax reaches the top when increasing more than 5 times amount of the spiral reinforcement. It is known that the influence of the spiral reinforcement depends on thickness ratio (t/D). In the case of filling the concrete into the hollow part of the pile, the shear strength increases by increasing the amount of spiral reinforcement. But the rising of the strength is smaller than the case of without concrete filling into the hollow part of the pile. Especially, in the case of the JPF12- type B, no relationship with the axial force, it shows an approximately constant value of the shear strength though the amount of the spiral reinforcement increases. It is because the failure mode is bending failure mode.

CONCLUSION

The following conclusions are evaluated from the experiment results:

1. In the case of the piles with the thick thickness and the low axial force, it shows stable deformation behavior even if the amount of spiral reinforcement increase by 5 times than the current JIS pile. And in the case of the high axial force, the deformation behavior doesn't improve till the amount of spiral reinforcement increases by more than 15 times.

2. In the case of filling the concrete into the hollow part of the present JIS pile, the displacement to the maximum strength of the pile becomes bigger when the thickness of the pile is thin. The declining of the strength after the maximum strength becomes gentle, too. The failure character is shear failure mode as the case of the present JIS pile.
3. In the case of filling the concrete into the hollow part of the pile and increasing the amount of spiral reinforcement, the maximum strength rise about 1.2 ~ 1.4 times under the low axial force. And the maximum strength rise 1.9 times as lease under the high axial force, the declining of the strength after the maximum strength becomes gentle.
4. The average shear stress at the maximum strength can be evaluated in some level by applying the ultimate shear strength formula of the column, but the amount of spiral reinforcement must be considered.
5. The influence of the composite axial stress on the average shear stress at the maximum strength is different because of the difference of the amount of spiral reinforcement in the case of no filling the concrete into the hollow part of the pile. But in the case of filling the concrete into the hollow part of the pile, the influence was the same regardless of the difference of the amount of spiral reinforcement.
6. The average shear stress at the maximum strength in the case of no filling the concrete into the hollow part of the pile rises when the amount of spiral reinforcement increases. But in the case of the large diameter piles, the average shear stress becomes constant even if the amount of spiral reinforcement increases by more than 5 times. In the case of filling the concrete into the hollow part of pile, the average shear stress becomes almost constant regardless the amount of spiral reinforcement.

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Appendix 1: Description of the Mark of the Specimens

Example JPE (1) 3 (2) -100 (3) -15 (4) -35 (5) -5 (6)

(1) E No filling concrete C Filling concrete
(2) 3 model of diameter 300ƒÓ 12 model of diameter 1200ƒÓ
(3) 80 Effective stress is Type B 100 Effective stress is Type C
(4) 15 Shear span to depth ration is 1.5
(5) 35 Axial force is 343kN 100 Axial force is 981kN
(6) 1 Standard amount of spiral reinforcement 5 5 times amount
10 10 times amount 15 15 times amount