Development of High Capacity Steel Tube Core for Micropiles

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ABSTRACT

Nowadays, the structure of micropile tends towards the type using steel tube core, which improves load performance of axial and bending resistance or bearing capacity as a pile under various applications. We develop high capacity steel tube core applicable to these types of micropiles. It consists of high tensile strength steel tube, protrusions on the surface of the tube for improving load-transfer capacity between the tube and surrounding grout block and thread coupling joints for rapid assembling in construction site. In order to confirm fundamental load performance of the core, some laboratory loading tests(compression, tensile, bending and bond tests) are conducted. Obtained results are as follows. 1)high tensile strength steel tube and thread coupling joints have enough mechanical strength. 2)welding protrusions on the surface of the tube does not affect on load-carrying charactarristics of this steel tube. 3)experimental values of yield and maximum loads in the compression, tensile and bending loading tests can be estimated by conventional design methods. 4)the steel tube with protrusions by welding bead shows still higher bond strength than the one with plane surface.

1. INTRODUCTION

Micropiling technology has been applied to tunnel lining reinforcement, and reinforcing existing foundations, e.g. underpinning, etc, mainly in Europe.

Now, in the United States, the micropile with high strength steel tube for oil well is used for seismic retrofit of bridge pier foundations, and in Japan, the one with steel tube for structural purposes was applied to L type retaining wall foundations. Therefore, the micropile tends towards a type of the one using steel tube core in order to improve mechanical strength as a pile by using steel tube's axial and bending load-capacity.

On the other hand, now new type of micropile, with high bearing capacity micropile gained under the large diameter of its improvement block by the jet grouting method, is examined for practical use. In the near future, this new type will be applied many fields.

We are now developing high capacity steel tube core, applicable to the micropile with high mechanical strength and that with high bearing capacity micropile. In this paper, we focus on its features and functions, and report some examined results.

2. FEATURES OF HIGH CAPACITY STEEL TUBE CORE

Fig. 1 shows features of the proposed high capacity steel tube core of a micropile. The core consists of steel tube, protrusions on the tube's surface, and joints. First, the tube core is high tensile steel tube for structural purposes(HT780). It is used for improving compression, tensile and bending load performance. Secondly, the protrusions are made of bead on the surface of the core in circumferential direction. They are used for improving load transfer performance between the core and surrounding grout block. Finally, the joints are thread coupling ones made by high tensile strength steel. Using them will result in rapid assembling in construction site.

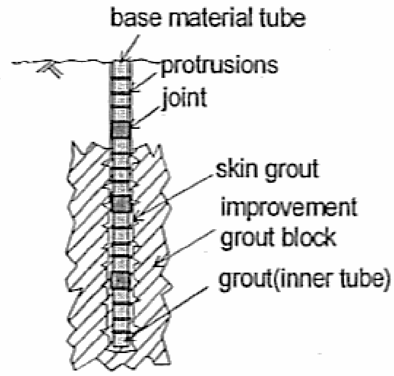


Fig. 1 features of the proposed core

3. LOADING CAPACITY TESTS OF CORE

3-1 Material Load Capacity Tests

We examine the core's performance against axial and bending load through some laboratory tests. The main purposes are as follows.

(1)to get knowledge of the tube core's bearing performance against compression, tensile, and bending load.

(2)to confirm the influence on the tube core's load performance in splicing the joints.

(3)to confirm the degree of increase in load performance in filling mortar into steel tube.

(4)to confirm the influence on the tube core's load performance in forming protrusions by welding bead.

(5)to examine the applicability of conventional design methods to estimate experimental yield and maximum loads.

(6)to understand the rigidities of the joint part against compression, tensile, and bending forces.

3-1.1 Summary of Tests

Table 1 shows technical properties of steel tube and Table 2 shows test cases. The steel tube is high tensile strength steel tube for structural purposes. The joint is thread coupling type which is usually used to splice high-grade-strength oil well tubes together. The protrusions are made by welding bead on the surface of the steel tube in the circumferential direction and their heights are approximately 2.5mm.

The test includes three kind of loading tests(axial compression, tensile and bending load tests). In the compression test, the length of specimen is 300mm(3D) in the case of no joint and 550mm in the case of spliced joint case(3D+joint's length). The lengths of specimens are 1000mm in the tensile test and 1200mm in the bending test. Load is simply increased in one direction.

Table 1 technical properties of core tube

material	high tensile strength steel tube(HT780)
diameter, thickness	φ 114.3, t8.6mm
ratio of radious to thickness(R/t)	6.65
yield strength by offset method	550～680N/mm^2
tensile strength	780N/mm^2 or more
mortar comprssive strength	σ 28=30N/mm^2

Table 2 test cases

features of specimens	test cases		
	compression	tensile	bending
steel tube	C-1	T-1	B-1
steel tube+joint	C-2	T-2	B-2
steel tube+mortar	-	-	B-3
steel tube+joint+mortar	C-3	-	B-4
steel tube+protrusions	-	-	B-5
length of specimens	C-1 :350mm C-2,3 :550mm	1000mm	1200mm

3-1.2 Test Results

(1) Axial compression test and tensile load test

Table 3 shows experimental yield load and maximum load of specimens from axial compression test and tensile load test respectively. Fig. 2 and Fig. 3 are load-displacement curve. Obtained results are as follows.

a) In the case of compression test, comparing the specimens C-1 and C-2, which differ in the point whether coupling joint is spliced or not, the loading performances show no clear difference. And both experimental values of yield and maximum load can be estimated by the product of measured offset yield strength and sectional area of the steel tube. On the other hand, local buckling in plastic zone at maximum load is observed in both cases. Therefore, this seems to indicate that this coupling joint have enough strength and basic behavior is determined by tube own and not by coupling joint.

b) Comparing the specimens C-2 and C-3 of compression test, which differ in the point whether mortar is filled in the steel tube or not, experimental yield and maximum loads of mortal-filled case are about 8% larger than those of no-mortar case and those values of mortar-filled case can be estimated by design method of total load of steel tube and mortar together.

c) About tensile test results of T-1 and T-2, which specimens differ in the point whether coupling joint is spliced or not, loading performances show no clear difference. And both experimental values of yield and maximum load nearly fit such design values as product of measured yield strength and sectional area of steel tube. On the other hand, experimental maximum loads in both specimens are determined by breaking at steel tube.

d) It is observed from Fig. 3 or Fig. 4 that the measured rigidity ratio of coupling joint case to only steel tube case is 0.9 in the compression test, and 1.5 in the tensile test.

Table 3 results of compression and tensile load tests

test method	test No.	results of observed(MN)		results of calculated(MN)	
		yield load*1)	maximum load	yield load	maximum load
compression	C-1(steel tube)	2.33(0.98)	2.62(1.05)	2.37(1.00)*2)	2.50(1.00)*4)
	C-2(joint)	2.33(0.98)	2.65(1.06)	2.37(1.00)*2)	2.50(1.00)*4)
	C-3(joint+mortar)	2.50(0.99)	2.88(1.09)	2.53(1.00)*3)	2.65(1.00)*5)
tensile	T-1(steel tube)	2.23(0.94)	2.48(0.99)	2.37(1.00)*2)	2.50(1.00)*4)
	T-2(joint)	2.25(0.95)	2.49(0.99)	2.37(1.00)*2)	2.50(1.00)*4)

attention: values inside ( ) are ratio of observed to calculated.

*1: values result from applying offset method to observed P- ε curves.

*2: values calculated with measured offset yield strength for test pieces.

*3: value calculated with measured offset yield strength and mortar compressive strength.

*4: values calculated with measured tensile strength for test pieces.

*5: values calculated with measured tensile strength and mortar compressive strength.

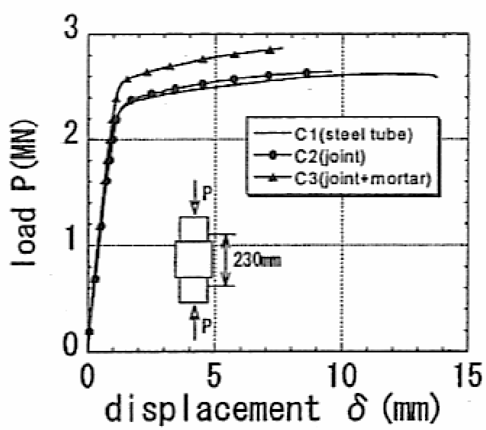


Fig. 2 load-displacement curve
(compression test)

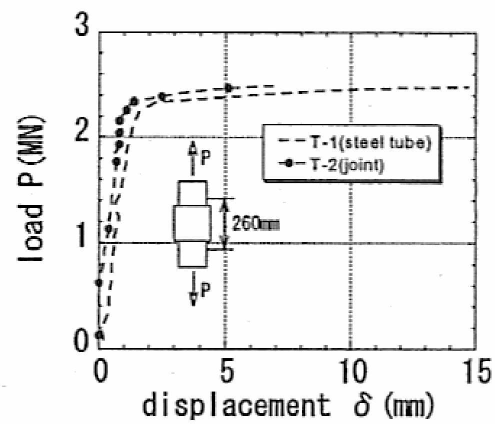


Fig. 3 load-displacement curve
(tensile test)

(2) Bending load tests

Fig. 4 shows a specimen and its measuring set-up for bending load test. Table 4 indicates the values of yield and maximum load. Fig. 5 and Fig. 6 are load-displacement curve at the center of specimen and M- ϕ curve calculated in the constant bending moment span. Further, strains of the specimens at the center part are also measured. Obtained results are as follows.

a) Comparing specimens B-1 and B-2, which differ in the point whether coupling joint is spliced or not, the loading capacity performances show no clear difference. And both experimental values of yield and maximum load nearly fit design loads calculated by measured offset yield strength. After yielding of the specimen in only tube case, its load decreases finally because the center section of the tube is flattened.

On the other hand, maximum load of coupling-joint case was determined by plastic local buckling on the tube aside the coupling joint.

b) Comparing the specimens B-1, B-3 and B-2, B-4, which differ in mortar is filled in the steel tube or not, experimental loads of mortar-filled case increases only by 2% to no-mortar case in both of coupling joint case and only tube case. In this test, it is considered that the mortar filled in the small diameter shares little load with the steel tube.

c) According to M- ϕ curves, which differ in the point whether coupling joint is spliced or not, show that elastic curvature of coupling joint case decreases by 20% to only steel tube case (no-joint case). Therefore, it is confirmed that the flexural rigidity (EI) of coupling joint is larger than that of steel tube .

d) Test results of specimen B-1 of plane surface show no clear difference compared with that of B-2 welded protrusions on its surface. Therefore welding bead on the surface of tube may not influence badly on load performance.

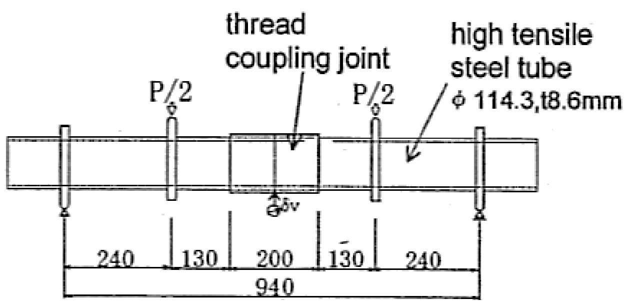


Fig. 4 outline of the test procedure

Table 4 results of benidnig tests

test No.	results of observed(KN・m)		results of calculated(KN・m)	
	yield moment*1)	maximum moment	yield moment	maximum moment
B-1(steel tube)	67.6(1.17)	78.4(0.98)	57.8(1.00)*2)	80.4(1.00)*4)
B-2(joint)	68.6(1.19)	81.3(1.01)	57.8(1.00)*2)	80.4(1.00)*4)
B-3(mortar)	68.6(1.19)	81.3(0.99)	57.8(1.00)*3)	82.3(1.00)*5)
B-4(joint+mortar)	70.6(1.22)	86.2(1.05)	57.8(1.00)*3)	82.3(1.00)*5)
B-5(protrusions)	69.6(1.20)	77.4(0.96)	57.8(1.00)*2)	80.4(1.00)*4)

attention: values inside ( ) are ration of observed to calculated.

*1: values when tensile side strain of specimens reach measured offset yield strain.

*2: values calculated with measured offset yield strength.

*3: values result from elastic-plastic calculation based on S-S curves of test pieces of steel tube and mortar

.*4: values calculated with measured offset yield strength supposing sttel tube are plastic state.

*5: maximum values calculated by method of above *3.

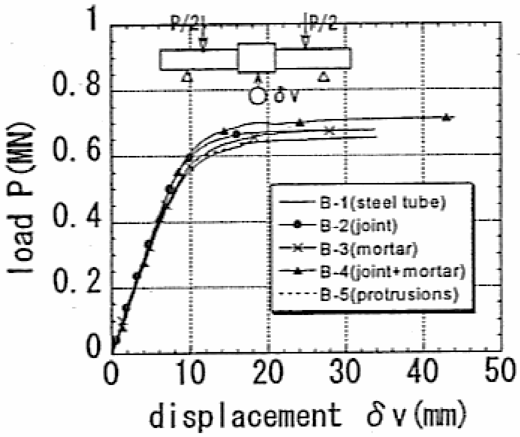


Fig. 5 load-displacement curve

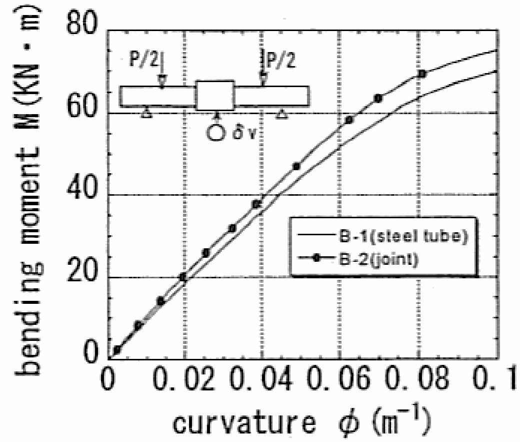


Fig. 6 M- ϕ curve

3-2 Bond Strength Tests

In order to make the micropile to act its full bearing capacity as a high capacity pile, axial force on the core must be transmitted from core's surface to outer body and surrounding soils. Therefore, the core is designed with protrusions to increase the bond strength of the core's surface and, some kind of bond tests are conducted to examine the bond strength of the core. The main purposes are as follows.

(1)to confirm the difference of bond performance between protrusions type and plain type.

(2)to examine the effect of the pitch of protrusions on bond performance.

3-2.1 Summary of test

Table 5 shows test cases and Fig. 7 shows outline of a specimen and test method. Specimens consist of steel bar which substitutes for the steel tube and pillar mortar block with 6D length (D=120mm) in diameter and height. And the steel bar is installed vertically into the mortar block with 2D un-bond length. Surface type of steel bar is two; i.e. one is protrusive type and the other is plane type. The former is with protrusions made of welding bead in the circumferential direction and the latter is original steel bar. Mortar type is also two; i.e. one is ordinal compressive strength type and the other is lower type. The former's strength is considered as skin grout's and the latter's is as improved mortar block's. Further, considering affect of surrounding soil's pressure on bond strength under actual conditions of the core, the mortar block is mainly enclosed by large steel pipe(ϕ 812.8,t9.5mm) . And the Loading is pulled-out type.

Table 5 test cases

test No.	surface	pitch of forming protrusions(mm)	mortar compressive strength(N/mm^2)		steel pipe	number
			ordinal	lower		
1	plane	-	28.1	-	on	2
2	protrusive*)	120	28.7	-	on	2
3		360	28.8	-	on	2
4		120	-	12.1	on	1
5			-	12.4	off	1
6		360	-	12.7	on	1

*: heights of protrusions are approximately 2.5mm.

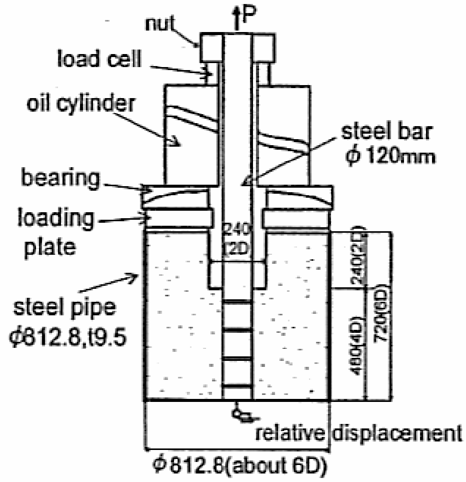


Fig. 7 outline of the test method

3-2.2 Test Results

(1) Influence of protrusions on the steel tube's surface on bond strength

Table 6 shows test results of bond strength- τ 0.2% and maximum bond strength- τ max altogether. Where, bond stress is the value which is obtained by dividing pull-out load by bond area of steel bar and τ 0.2% is the value when relative displacement on the bottom of the steel bar reaches 0.2% of the steel bar's diameter. Fig. 8 shows bond stress - relative displacement curves. Obtained results are as follows

a) Focusing on the results of No.1, No.2 and No.3, which differ in the condition of welding protrusions or not, it is confirmed that bond strength- τ 0.2% of protrusive type is 1.5-1.9 times as large as that of plane type. Therefore, forming protrusions on the surface of the steel bar results in improving bond strength.

b) Focusing on the results of No.2, No.3, No.4 and No.5, which differ in pitch of forming protrusions, it is also confirmed that bond strength (both τ 0.2% and τ max)of pitch-120mm are larger than that of pitch-360mm regardless of difference in mortar strength. Therefore, it is certain that bond performance can be improved in proportion to the number of protrusions.

c) Protrusive types have better displacement curve because bond stress does not decrease so much when their relative displacements increase.

d) Comparing the test results of No.4 and No.5, which differ in the point whether the mortar is enclosed by steel pipe or not, it is confirmed that bond stress of no-steel-pipe case reaches τ max in smaller displacement range and both cases have almost the same bond strength- τ 0.2% and displacement curve within this range.

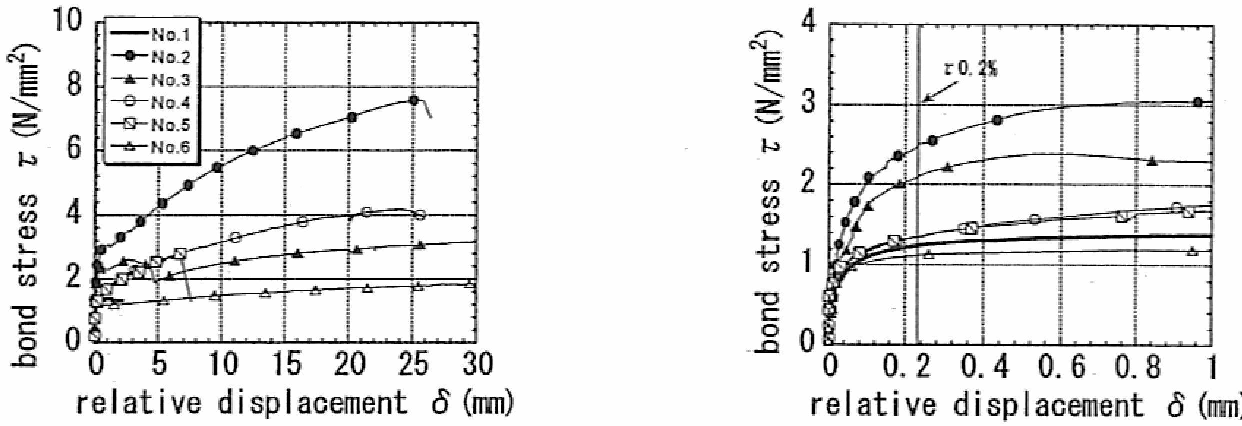
Table 6 test results

test No.	surface	pitch of forming protrusions(mm)	mortar compressive strength	steel pipe	bond strength(N/mm^2)*1)	
					τ 0.2%	τ max
1	plane	-	ordinal	on	1.4(1.0)	1.5(1.0)
2	protrusive	120		on	2.6(1.9)	7.4(4.9)
3		360		on	2.1(1.5)	2.5(1.7)*2)
4		120	lower	on	1.4	4.2
5				off	1.4	2.8
6		360		on	1.1	2.2*2)

attention: values inside ( ) are ratio of protrusive type to plane type.

*1: average values.

*2: values when tests finished



(a) the whole of loading (b) τ 0.2%

Fig. 8 bond stress-relative displacement curves

(2)Influence of steel pipe's confining pressure on bond strength.

Fig.9 shows confining pressure to the mortar block - τ 0.2%, τ max dialogue(No.4,No.5) . Where, confining pressures in the cases of enclosed by steel pipe are calculated from average strain measured circumferentially on the steel pipe's outside (applying the structural formula of piller shell). Obtained results are follows.

a) Examining τ 0.2% values between with steel pipe case and no steel pipe, it is confirmed that confining pressure of the former is only about 0.03N/mm^2 and that their bond strength are almost the same. Therefore, there may be no affect of confining by steel pipe on the bond strength of τ 0.2%.

b) Examining τ max values, it is confirmed that confining pressure of with steel pipe case is approximately 0.5N/mm^2. Assuming micropiles are driven at the depth of 10 meters, earth pressure at rest 0.09N/mm^2 acts (assuming γ_t=18kN/m^3 and K0=0.5). Therefore, under such pressure, τ max may be approximately 10% larger than that of no steel pipe case.

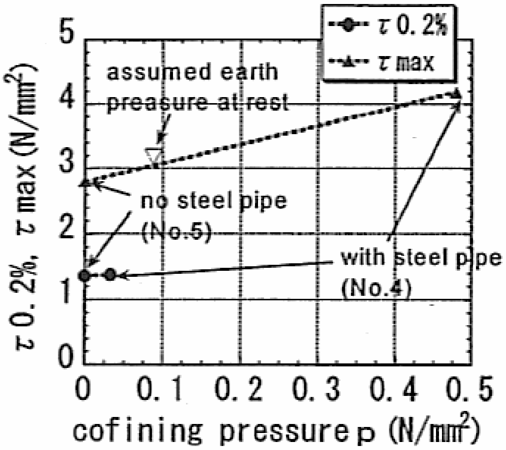


Fig. 9 confining pressure- τ 0.2%, τ max diagram

4. CONCLUSION

This paper reports the summary of high capacity steel tube core for high mechanical capacity and high bearing capacity micropiles and the results of some laboratory tests for confirming its basic load performance. Obtained results are as follows.

(1)Thread Coupling joint has larger mechanical strength than steel tube of the core.

(2)Forming protrusion by welding bead on the steel tube's surface does not influence on the load performance of steel tube.

(3)Filling mortar in steel tube, load performance for axial compression increases about 8% to no mortar case , but against bending loading only about 2% in this test.

(4)The experimental loads(yield load, maximum load) of each part of the core can be estimated by conventional design methods.

(5)The tube core with protrusive surface has larger bond strength and displacement performance than the one without protrusions.

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